Study of Nucleon Spin and TMDs at JLab

J. P. Chen , Jefferson Lab

DSPIN-13, Dubna, Russia, October 8-12, 2013

- **Nucleon Spin Study**
  - g_2 structure function and its moment (d_2): higher-twist effects
- **TMDs with 6 GeV JLab: Exploration**
  - Recent and preliminary results from Hall A (transversely Polarized ^{3}He (n))
    - Collins/Sivers/Worm-gear asymmetries on pions and Kaons
    - **Inclusive hadron and electron SSA**
- **Plan at JLab 12 GeV for TMD study: Precision Multi-d Mapping**
  - **SoLID Program on TMDs**
- **Long-term Future: TMDs study with Electron-Ion Colliders (EIC)**
  - **A New Opportunity: an EIC in China (EIC@HIAF)**

Jefferson Lab at a Glance

CEBAF

- **High-intensity** electron accelerator based on **CW SRF** technology
- **E_{max} = 6 GeV** →**12 GeV**
- **I_{max} = 200 μA**
- **Pol_{max} = 85%**

- ~ **1400** Active Users
- ~ **800** FTEs
- **178** Completed Experiments @ 6 GeV
- Produces **~1/3** of US PhDs in Nuclear Physics

JLab Spin Experiments

- Earlier JLab Spin Results (not covered in this talk)
  - Spin Asymmetry A_1 /g_1 in the Valence (High-*x)* Region
  - Spin Moments: Spin Sum Rules and Polarizabilities,
  - Spin Structure in the Resonance Region
  - Reviews: S. Kuhn, J. P. Chen, E. Leader, Prog. Part. Nucl. Phys. 63, 1 (2009)
- This Talk Focus on Beyond Polarized PDF (g_1)

  Recent experiments with transversely polarized targets
  - **g_2 measurements to extract d_2 (Color Polarizability/Lorentz Force)**
  - **Exploratory measurements of TMDs with a transverse/vertical polarized target**
- 12 GeV Program: SoLID, Precision Multi-d Mapping of SSA/TMDs

Beyond Polarized PDFs:
Higher-Twist Effects
Study Quark-Gluon Correlations

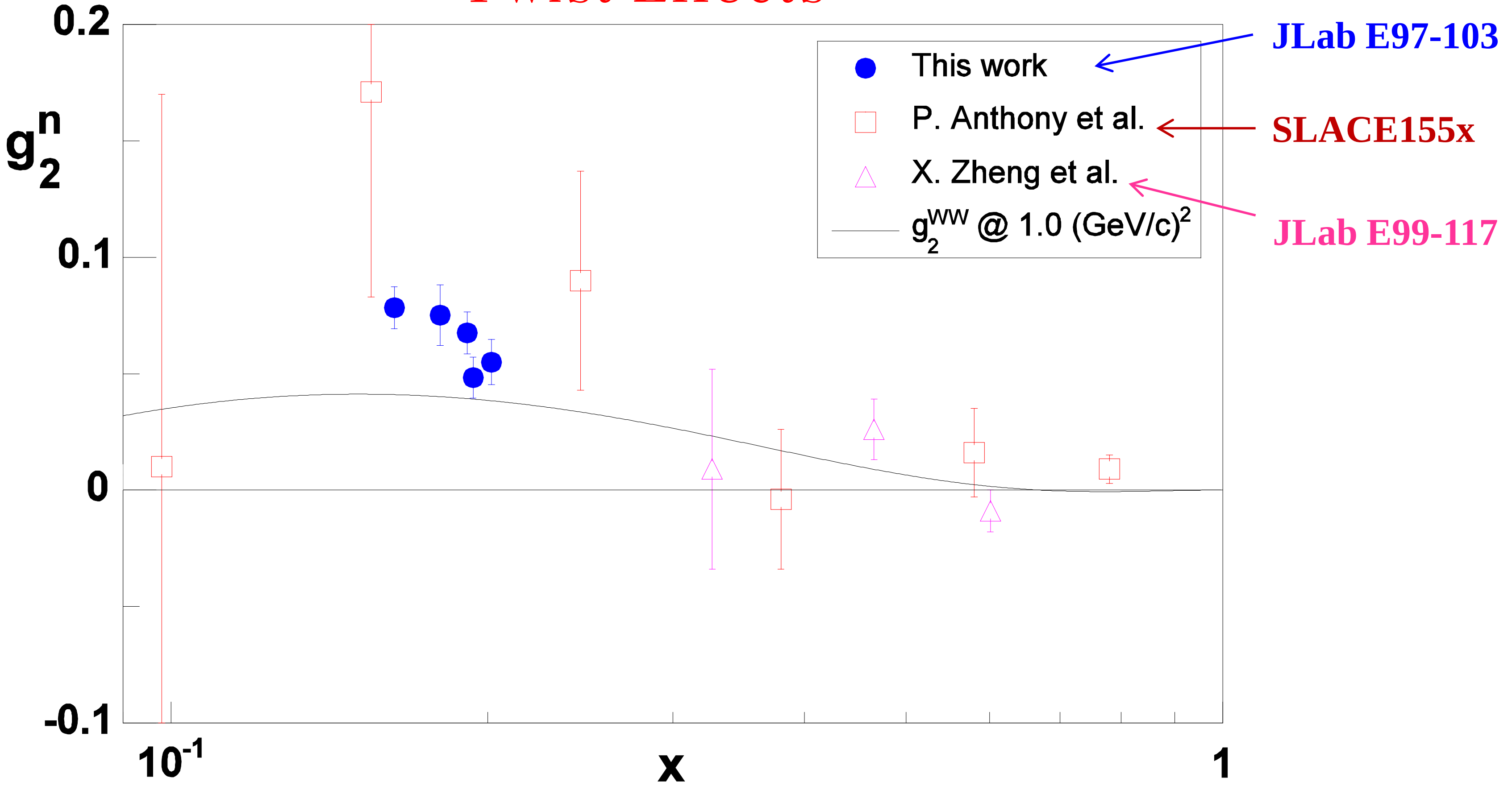
g_2 (d_2) from JLab

Measurements of g_2 and Its Moments

g_2 measurements need transversely polarized targets, experimentally difficult
0^{th} moment (no x weighting): Burkhardt-Cottingham Sum Rule, valid at all Q2
2^{nd} moment (x2 weighting): high Q^2, d_2, twist-3 color polarizability or Lorentz force, LQCD
low Q^2, LT-spin polarizability, test ChPT

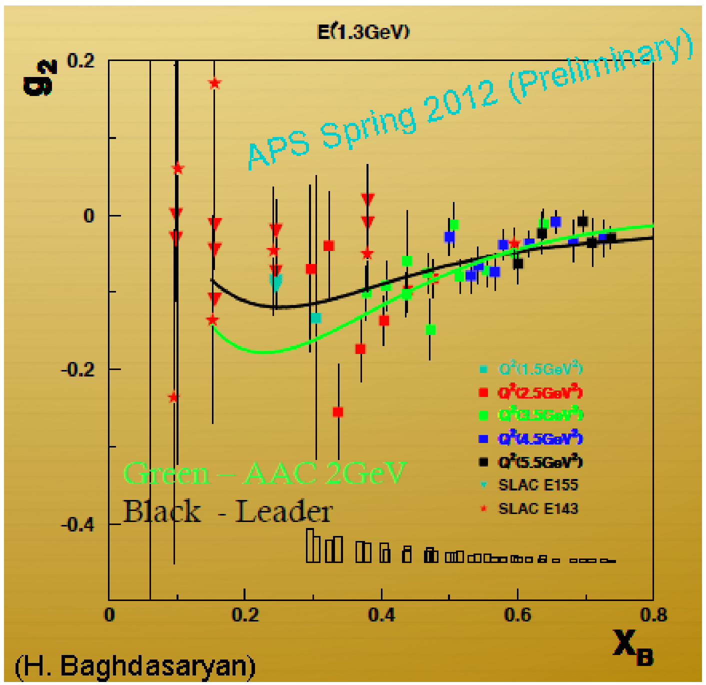
- Only dedicated measurement before JLab was SLAC E155x
  - not high precision, wider range of Q^2 for moment
- g_2 on the neutron (^{3}He) in Hall A (6 experiments)
  - E97-103: W>2 GeV, Q^2~ 1 GeV^2, x ~0.2, study higher-twist (published)
  - E99-117: W>2 GeV, high Q^2 (3-5 GeV^2) (published)
  - E94-010: moments at low Q^2 (0.1-1 GeV^2) (published)
  - E97-110: moments at very low Q^2 (0.02-0.3 GeV^2) (preliminary)
  - E01-012: moments at intermediate Q^2 (1-4 GeV^2) (submitted)
  - E06-014: moments at high Q^2 (2-6 GeV^2) (analysis)
- g_2 on the proton
  - in Hall C
    - RSS: moments at intermediate Q^2 (1-2 GeV^2) (published)
    - SANE: moments at high Q^2 region (2.5-6.5 GeV^2) (analysis)
  - in Hall A
    - g2p: moments at very low Q^2 (0.02-0.3 GeV^2) (analysis)

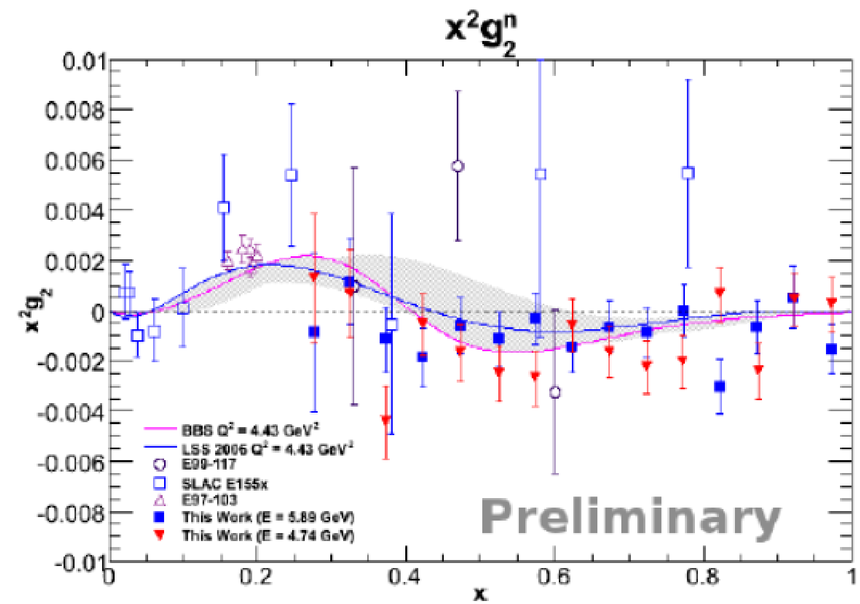
Earlier Measurement of $g_2^n(x,Q^2)$: Search for Higher Twist Effects



- Deviation from g_2^{WW} → Twist-3 (or higher)
- Measure higher twist → quark-gluon correlations.
- Hall A E97-103, K. Kramer *et al.*, PRL 95, 142002 (2005)

g_2 in DIS and Resonances



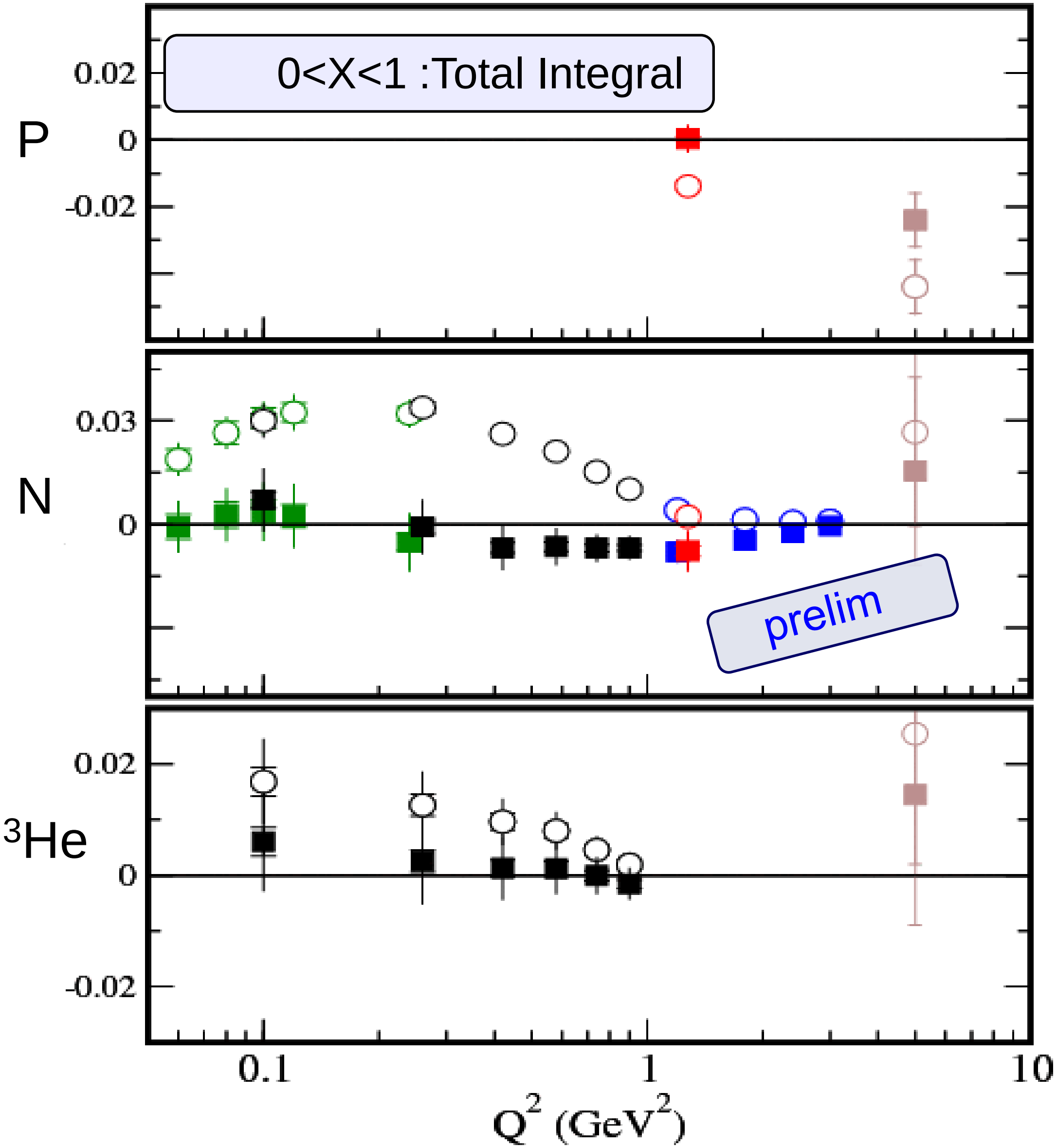


(M. Posik) (No external radiative corrections)

- Proton (NH_3)
  - Hall C SANE (E07-003)
  - $0.3 < x < 0.8 \quad 2.5 < Q^2 < 6.5$

- Neutron (on ^3He)
  - Hall A d2n (E06-014)
  - 4.7 and 5.9 GeV beam

Burkhardt-Cottingham Sum Rule



$$\Gamma_2 = \int_0^1 g_2(x)dx = 0$$

Brawn: SLAC E155x

Red: Hall C RSS

Black: Hall A E94-010

Green: Hall A E97-110 (preliminary)

Blue: Hall A E01-012 (preliminary)

BC = Meas+low_*x*+Elastic

"Meas": Measured x-range

"low-*x*": refers to unmeasured low x part of the integral. Assume Leading Twist Behaviour

Elastic: From well know FFs (<5%)

Color Lorentz Force (Polarizability): d_2

- 2^{nd} moment of g_2-g_2^{WW}

  d_2: twist-3 matrix element

$$d_2(Q^2) = 3\int_0^1 x^2[g_2(x,Q^2) - g_2^{WW}(x,Q^2)]dx$$

$$= \int_0^1 x^2[2g_1(x,Q^2) + 3g_2(x,Q^2)]dx$$

d_2 and g_2-g_2^{WW}: clean access of higher twist (twist-3) effect: *q*-*g* correlations

Color polarizabilities χ_E, χ_B are linear combination of d_2 and f_2

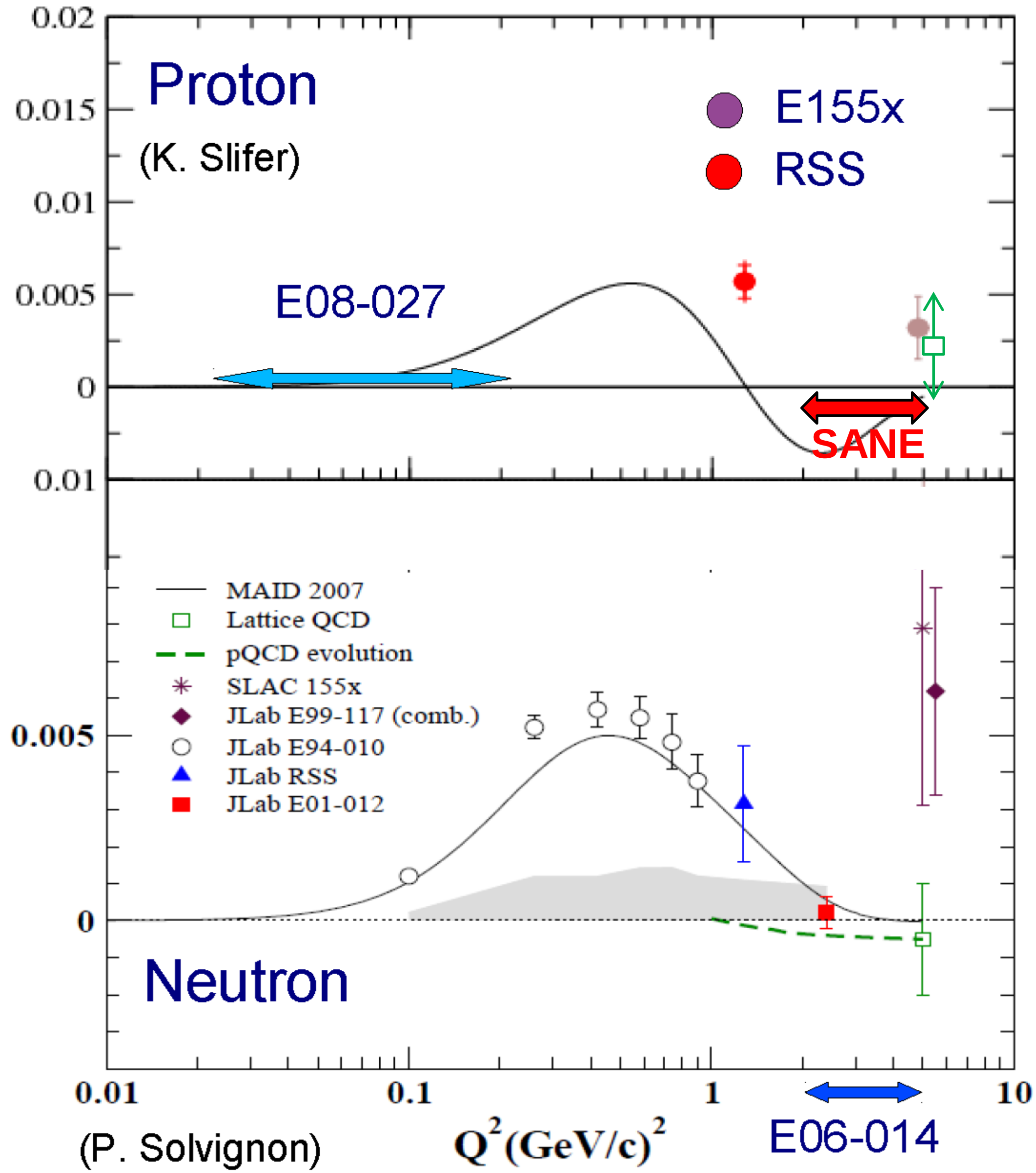
Provide a benchmark test of Lattice QCD at high Q^2

Avoid issue of low-*x* extrapolation

Related to Sivers Function?

d_2 Measurements Comparison with Lattice

- d_2 moments for p and n
- Only contributions from the measurement region
- Elastic not included (only important for $Q^2 < 2$ GeV^2)
- Contributions from unmeasured Low x region usually not significant due to x^2 weighting

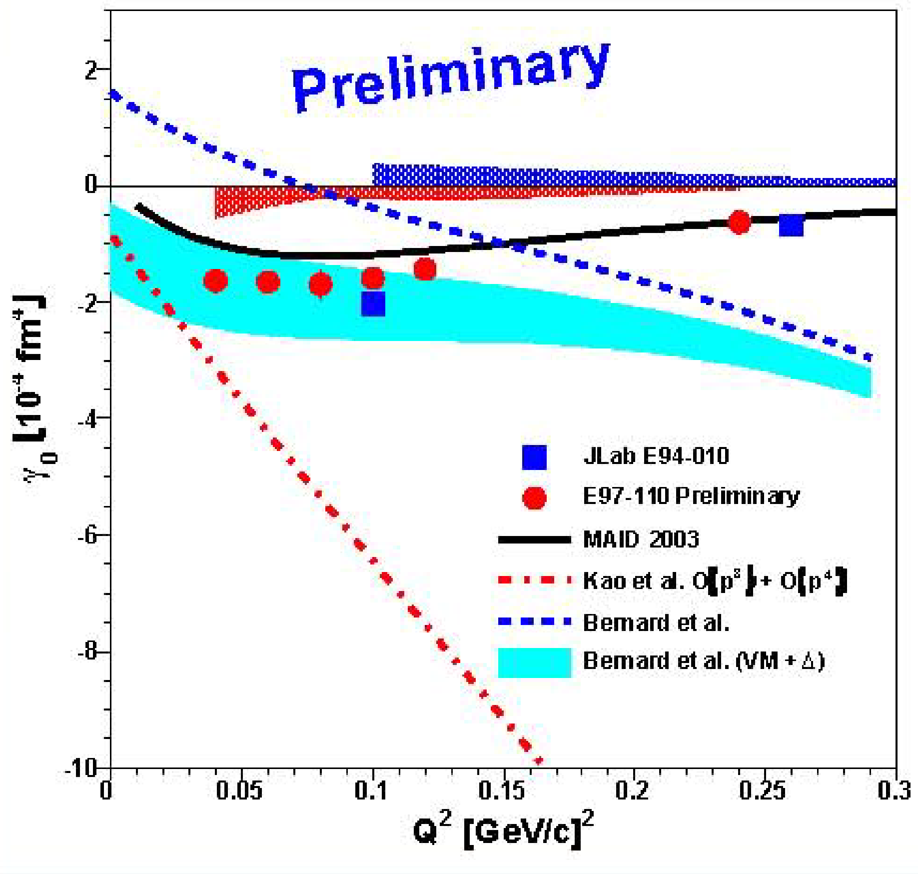


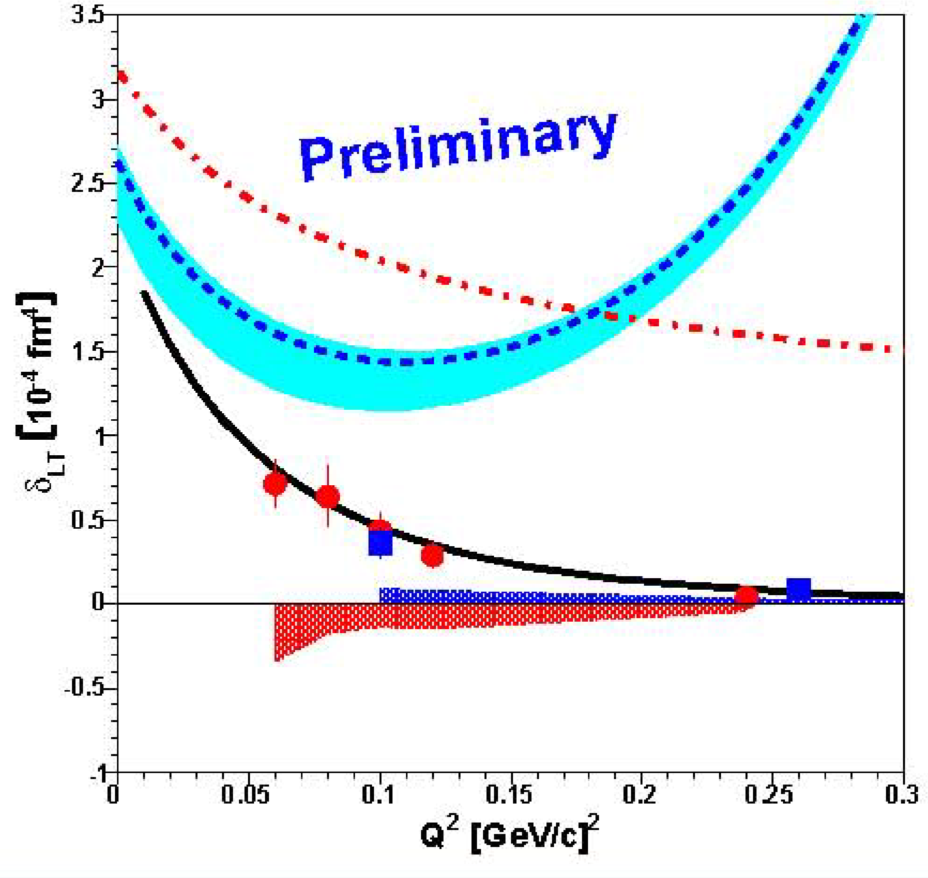
Spin Polarizabilities

Preliminary E97-110 (and Published E94-010)

Spokesperson: J. P. Chen, A. Deur, F. Garibaldi, plots by V. Sulkosky

- **Significant disagreement between data and both ChPT calculations for δ_{LT}**
- Good agreement with MAID model predictions

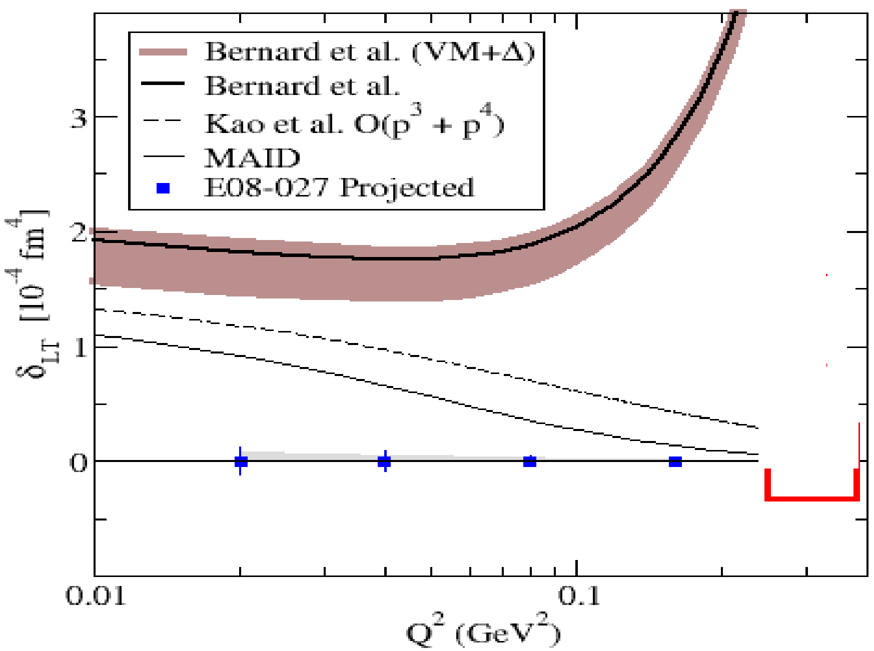




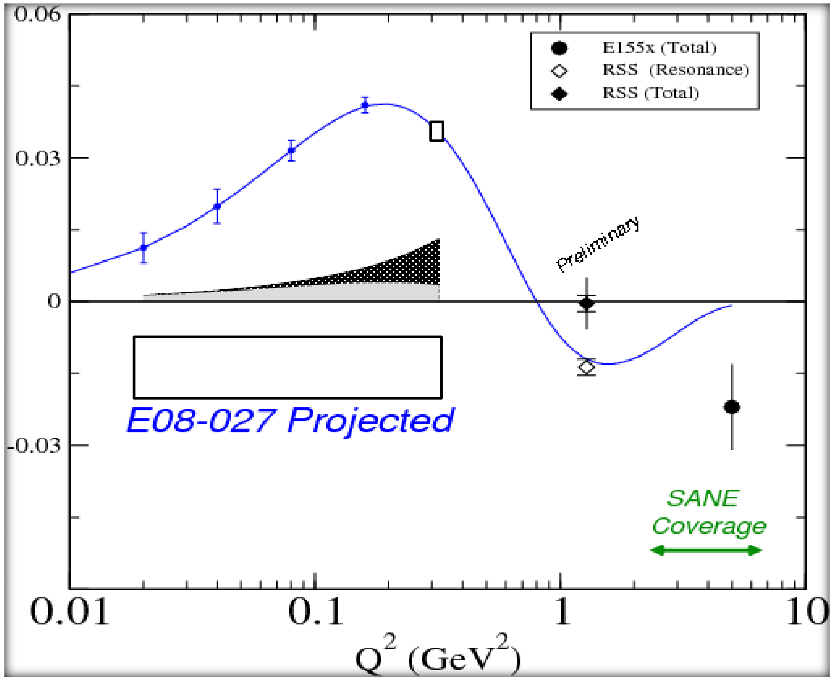
E08-027: g_2^p at low Q^2

Spokespersons: A. Camsonne, J. P. Chen, D. Crabb, K. Slifer
7 PhD Students

LT Spin Polarizability



BC Sum Integral Γ_2



Main goals:

1) Test Chiral PT calculations: large discrepancy for neutron δ_{LT}
2) BC Sum Rule: violation suggested for proton at large Q2, ok for neutron
3) Input to Hydrogen Hyper Fine Splitting/ Proton Radius

Data taken in 2012. Analysis underway.

Summary on g_2 Study

Extensive measurements of g_2 on the proton and neutron (^{3}He) from JLab

1) Observed deviation from g_2^{WW} → higher-twist (twist-3) effects
quark-gluon correlations
2) BC Sum Rule: violation suggested for proton at large Q^2 from SLAC E155x
ok at low Q^2 for proton and ok for neutron over wide range
3) d_2 moment: study higher-twist (twist-3), comparison with LQCD
~2σ discrepancy on the neutron from SLAC E155x and JLab E99-117
at large Q^2,
ok at low Q^2
results for the proton (SANE) and neutron (E06-014) soon.
4) LT spin-polarizability (δ_{LT}): test Chiral PT calculations.
large discrepancy for the neutron δ_{LT}
proton data taken, results soon.

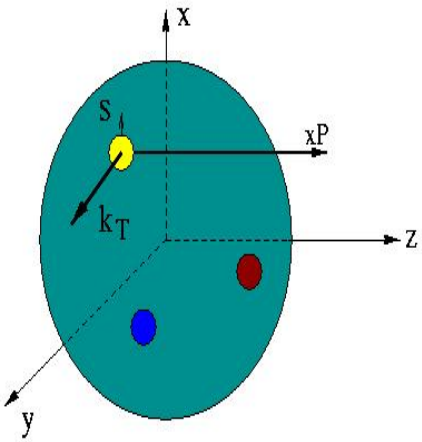
Single Spin Asymmetries with A Transversely Polarized ^3He (n)

JLab Hall A E06-010

Unified View of Nucleon Structure

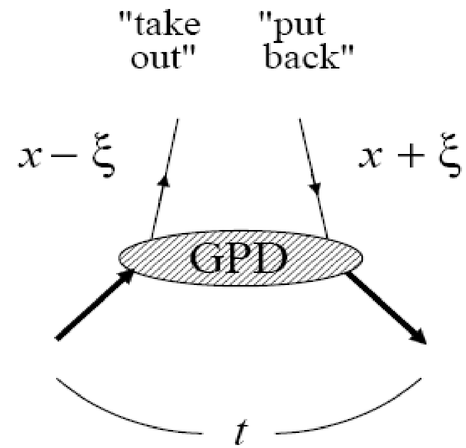
$W_p^u(x,k_T,r)$ Wigner distributions

5D Dist.



d^2r_T

d^2k_T



TMD PDFs

$f_1^u(x,k_T)$, ..

$h_1^u(x,k_T)$

GPDs/IPDs

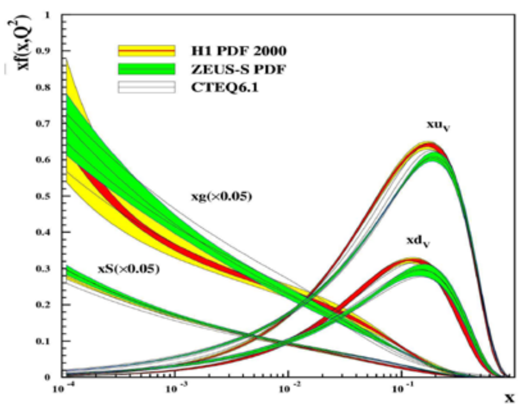
3D imaging

d^2k_T

d^2r_T

dx &

Fourier Transformation



PDFs

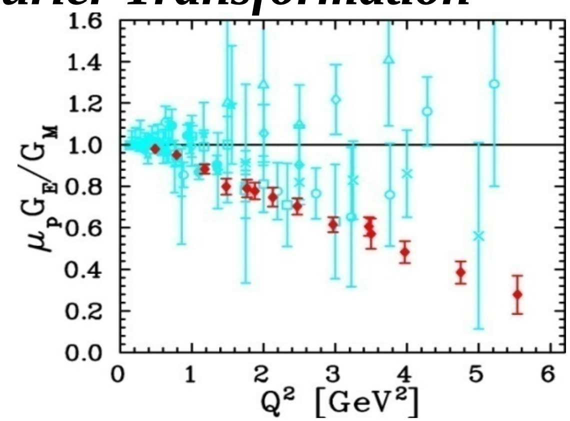
$f_1^u(x)$, .. $h_1^u(x)$

1D

Form Factors

$G_E(Q^2)$,

$G_M(Q^2)$



Leading-Twist TMD PDFs

Nucleon Polarization		Quark polarization		
		Unpolarized (U)	Longitudinally Polarized (L)	Transversely Polarized (T)
	U	$f_1 =$		$h_1^{\perp} = \quad - \quad$ *Boer-Mulders*
	L		$g_1 = \quad - \quad$ *Helicity*	$h_{1L}^{\perp} = \quad - \quad$ *Worm Gear*
	T	$f_{1T}^{\perp} = \quad - \quad$ *Sivers*	$g_{1T} = \quad - \quad$ *Worm Gear*	$h_1 = \quad - \quad$ *Transversity* $h_{1T}^{\perp} = \quad - \quad$ *Pretzelosity*

Nucleon Spin

Quark Spin

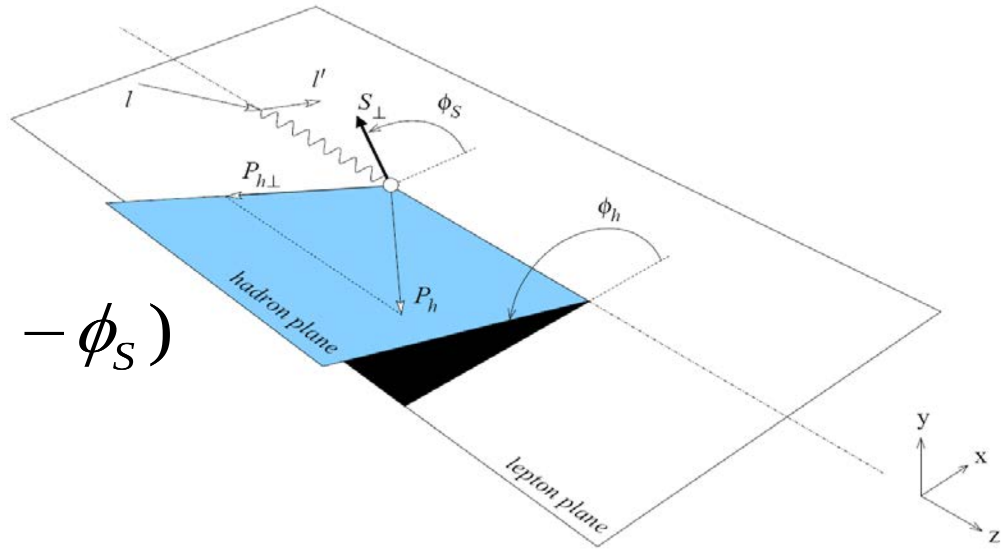
: *Probed with transversely pol target*
HERMES, COMPASS, JLab E06-010

Separation of Collins, Sivers and pretzelocity effects through angular dependence

$$A_{UT}(\varphi_h^l, \varphi_S^l) = \frac{1}{P}\frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$

$$= A_{UT}^{Collins}\sin(\phi_h + \phi_S) + A_{UT}^{Sivers}\sin(\phi_h - \phi_S)$$

$$+ A_{UT}^{Pretzelosity}\sin(3\phi_h - \phi_S)$$



$$A_{UT}^{Collins} \propto \langle \sin(\phi_h + \phi_S) \rangle_{UT} \propto h_1 \otimes H_1^{\perp}$$

$$A_{UT}^{Sivers} \propto \langle \sin(\phi_h - \phi_S) \rangle_{UT} \propto f_{1T}^{\perp} \otimes D_1$$

$$A_{UT}^{Pretzelosity} \propto \langle \sin(3\phi_h - \phi_S) \rangle_{UT} \propto h_{1T}^{\perp} \otimes H_1^{\perp}$$

E06-010 Experiment

$$^3He^{\uparrow}(\vec{e},e'\pi^{\pm})X$$

$$^3He^{\uparrow}(\vec{e},e'K^{\pm})X$$

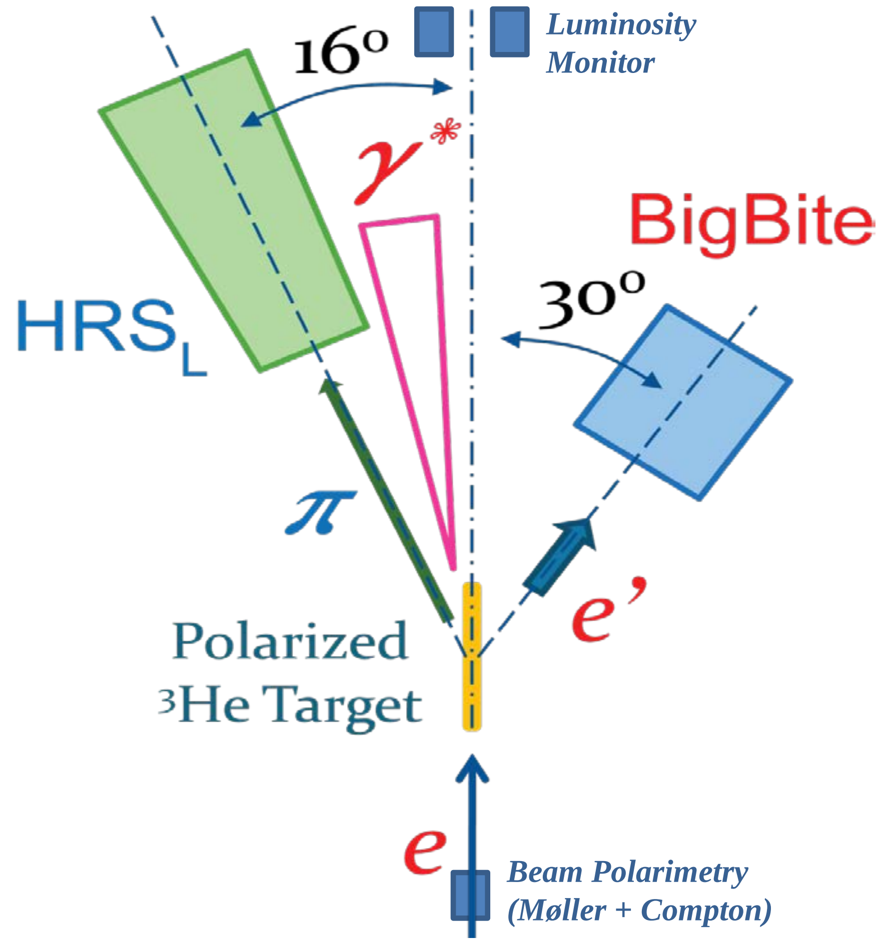
Spokespersons: J. P. Chen/E. Cisbani/H. Gao/X. Jiang/J. C. Peng

7 PhD Thesis Students (graduated) + 2 new students

- **First measurement on n (^{3}He)**
- Transversely Polarized ^{3}He Target
- Polarized Electron Beam, 5.9 GeV

- BigBite at 30º as Electron Arm
  - P_e = 0.7 ~ 2.2 GeV/c

- HRS$_L$ at 16º as Hadron Arm
  - P_h = 2.35 GeV/c
  - Excellent PID for π/K/p



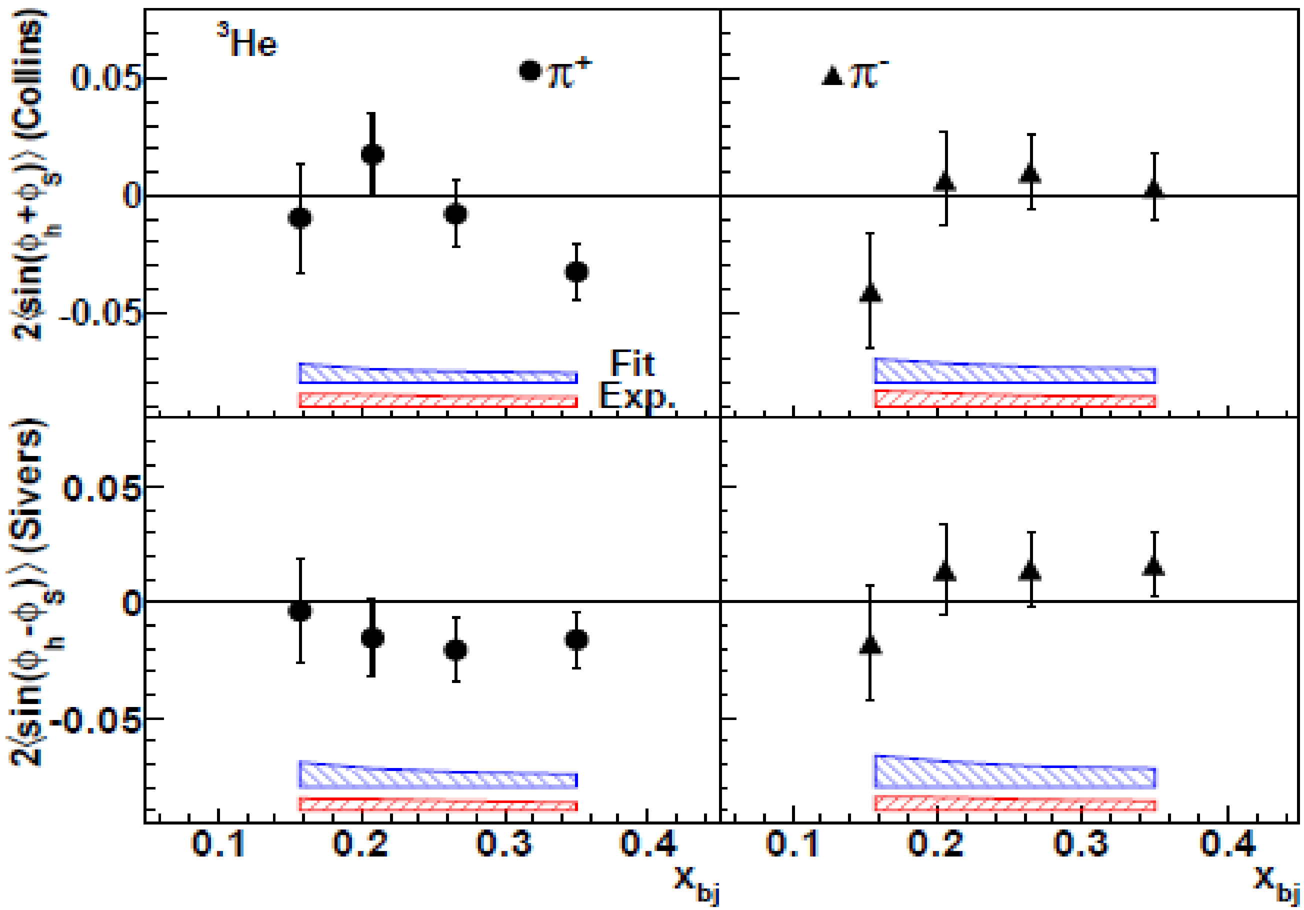
Published Results: from JLab Hall A E06-010
with a Transversely Polarized ^{3}He (n)

Collins/Sivers Asymmetries on $\pi+/\pi-$
Worm-Gear II: Trans-helicity on p+/p-

E06-010 # ^{3}He Target Single-Spin Asymmetry in SIDIS

X. Qian at al., PRL 107:072003(2011)

$$^3\mathrm{He}^{\uparrow}(e, e'h),\ \ h = \pi^+, \pi^-$$

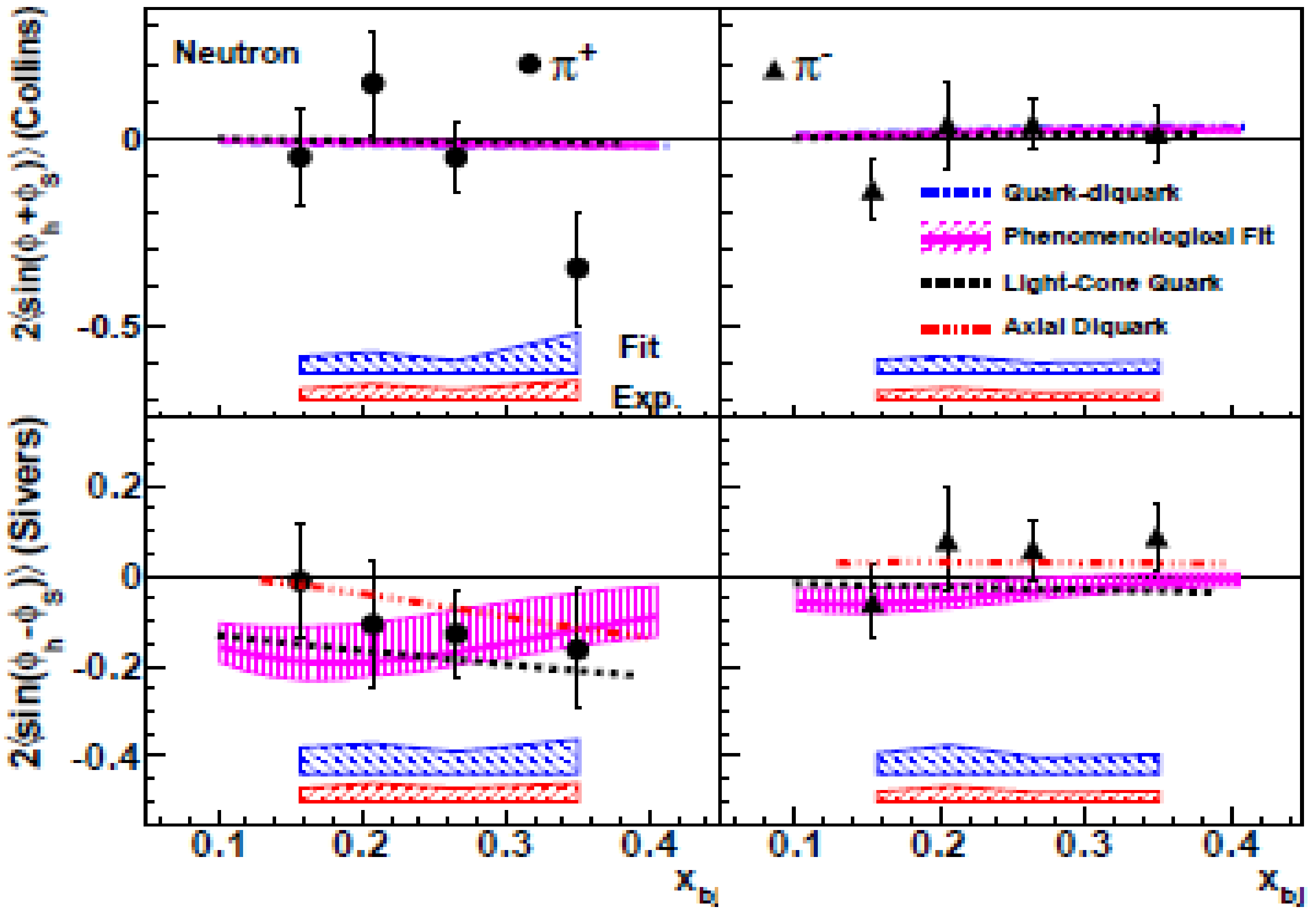


^{3}He Collins SSA small
Non-zero at highest x for π+

^{3}He Sivers SSA:
negative for π^+,

Blue band: model (fitting) uncertainties
Red band: other systematic uncertainties

Neutron Results with Polarized ^{3}He from JLab



Collins

asymmetries are not large, except at x=0.34

Sivers

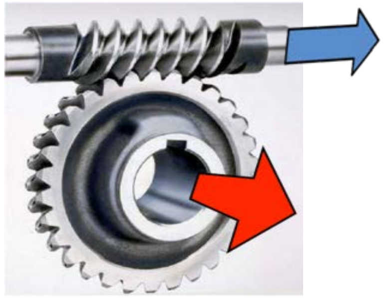
π^+ $(u\bar{d})$ negative agree with Torino fit

Blue band: model (fitting) uncertainties

Red band: other systematic uncertainties

Asymmetry A_{LT} Result

J. Huang et al., PRL. 108, 052001 (2012).

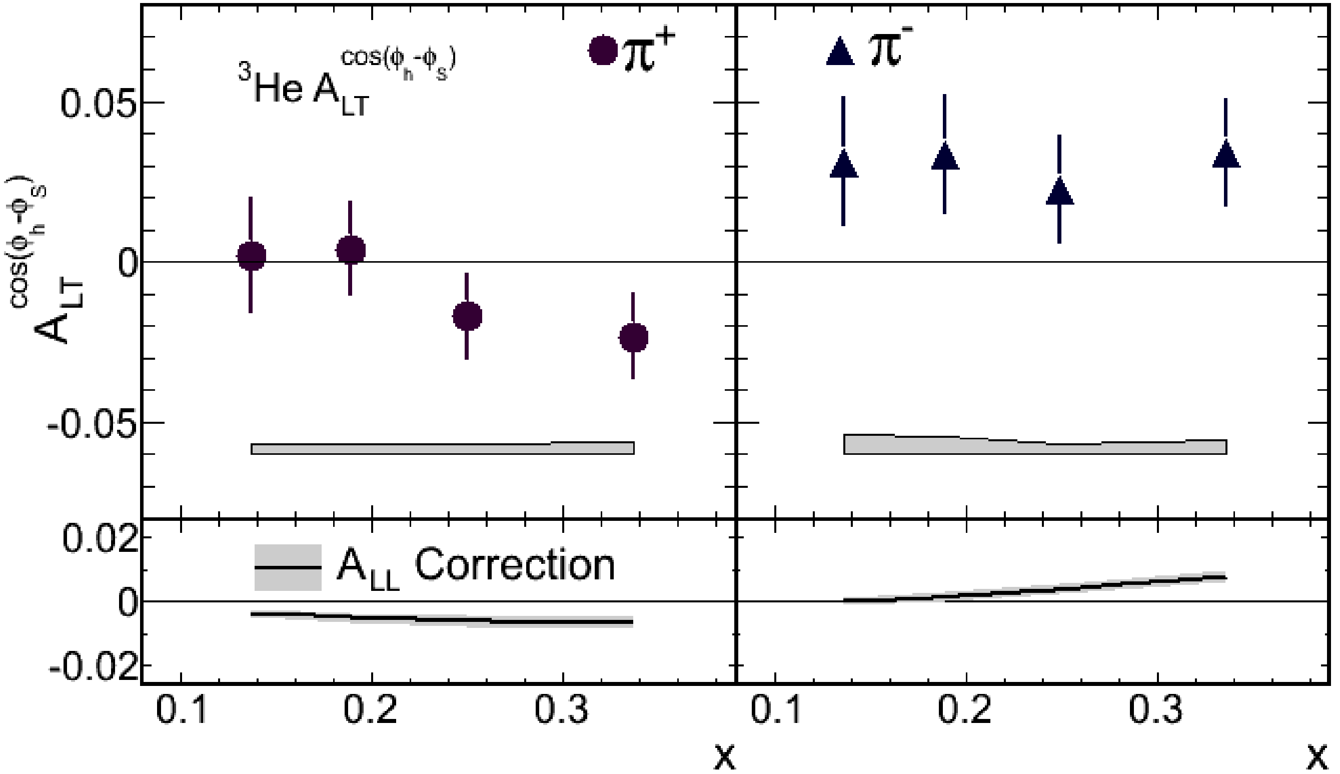


Worm-Gear.

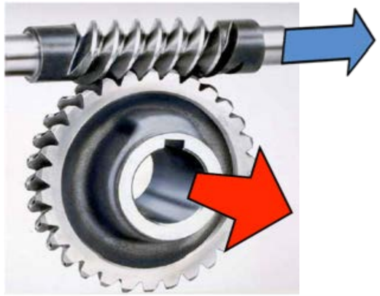
To leading twist:

$$A_{\mathrm{LT}}^{\cos(\phi_h-\phi_s)} \propto F_{LT}^{\cos(\phi_h-\phi_s)} \propto g_{1T}^{q} \otimes D_{1q}^{h}$$

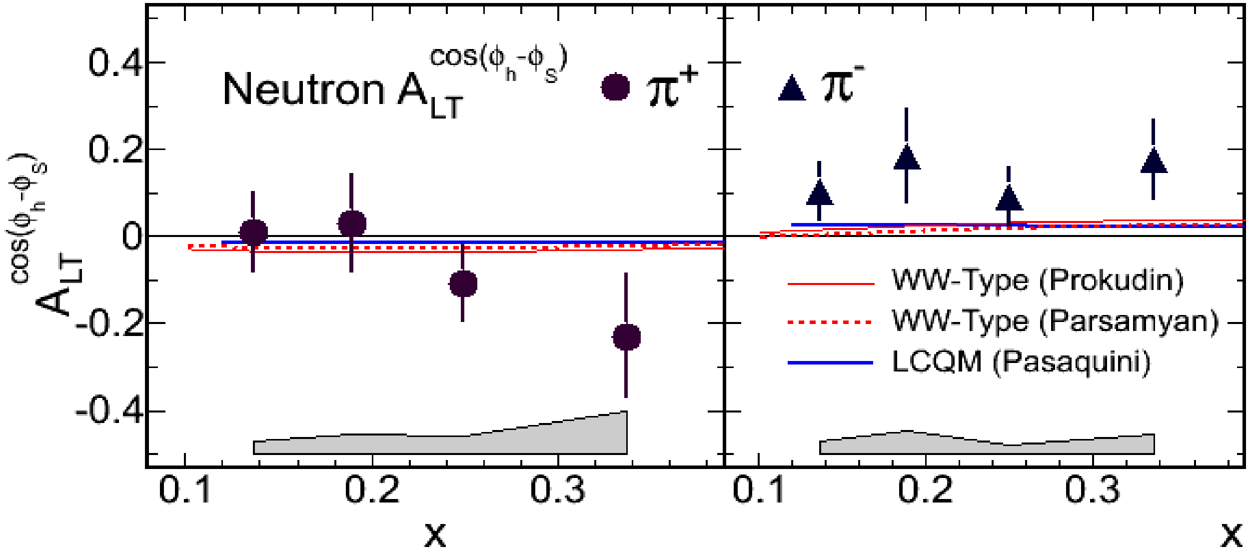
- ^{3}He A_{LT} : **Positive for π-**



Neutron A_{LT} Extraction



- $$A_{LT}^{^3\mathrm{He}} = P_n \frac{\sigma_n}{\sigma_{^3\mathrm{He}}} A_{LT}^n + P_p \frac{2\sigma_p}{\sigma_{^3\mathrm{He}}} A_{LT}^p \qquad \begin{cases} P_n = 0.86^{+0.036}_{-0.02} \\ P_p = -0.028^{+0.009}_{-0.004} \end{cases}$$
  - Corrected for proton dilution, f_p
  - Predicted proton asymmetry contribution < 1.5% (π^+), 0.6% (π^-)
- $$A_{\mathrm{LT}}^n \propto g_{1T}^q \otimes D_{1q}^h$$ *Trans-helicity*
  - Dominated by L=0 (S) and L=1 (P) interference
- Consist w/ model in signs, suggest larger asymmetry



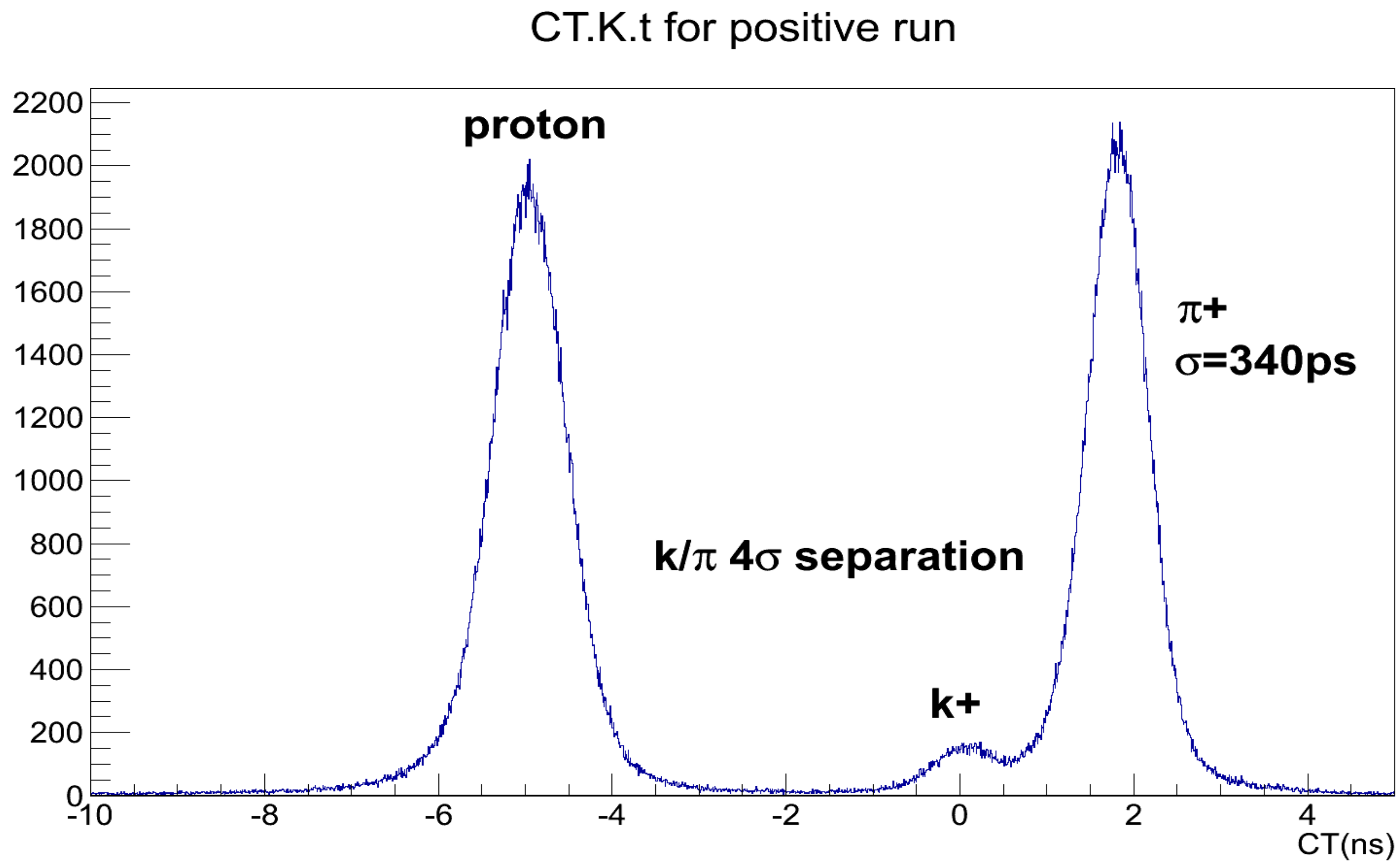
Preliminary New Results (I) from JLab Hall A E06-010 with a Transversely Polarized ^3He (n)

Collins/Sivers Asymmetries on K+/K-

Analysis by Y. Wang (UIUC) , Y. Zhao (USTC)

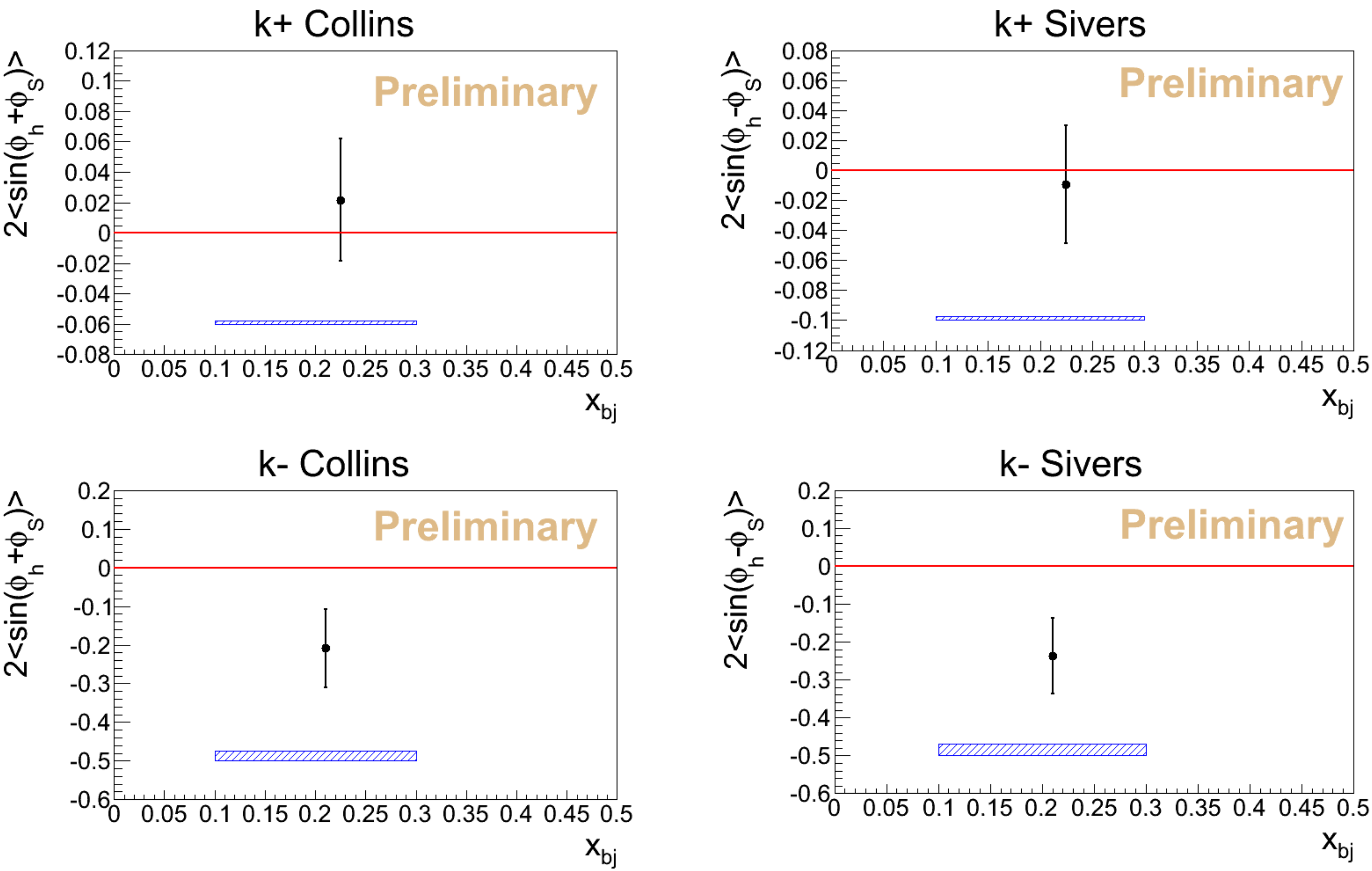
Kaon PID by Coincidence time of flight

Cross checked with RICH results



K+/π+ ratio: ~5%   K-/π- ratio: ~1%

Preliminary K+/K- Collins and Sivers Asymmetries on ^3He

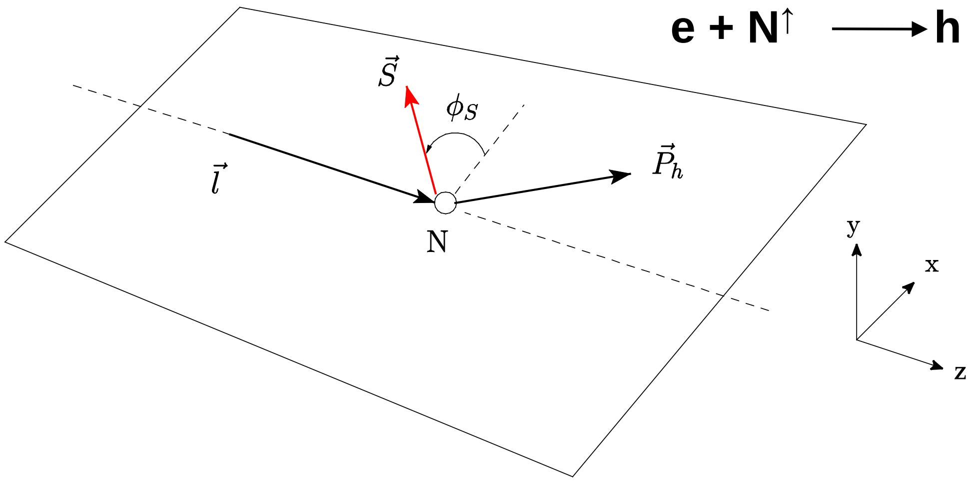


Preliminary New Results (II) from JLab Hall A E06-010 with a transversely polarized ^{3}He (n)

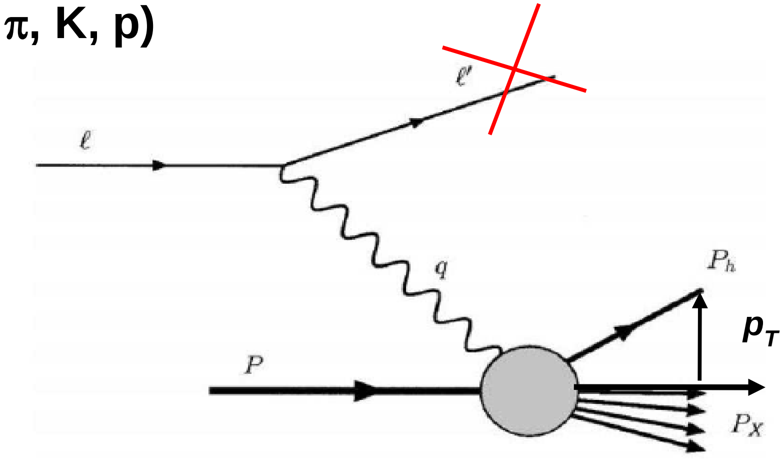
Inclusive Hadron SSA

Analysis by K, Allada (JLab), Y. Zhao (USTC)

Inclusive Hadron Electroproduction



e + N$^\uparrow$ $\longrightarrow$ h + X **(h = π, K, p)**



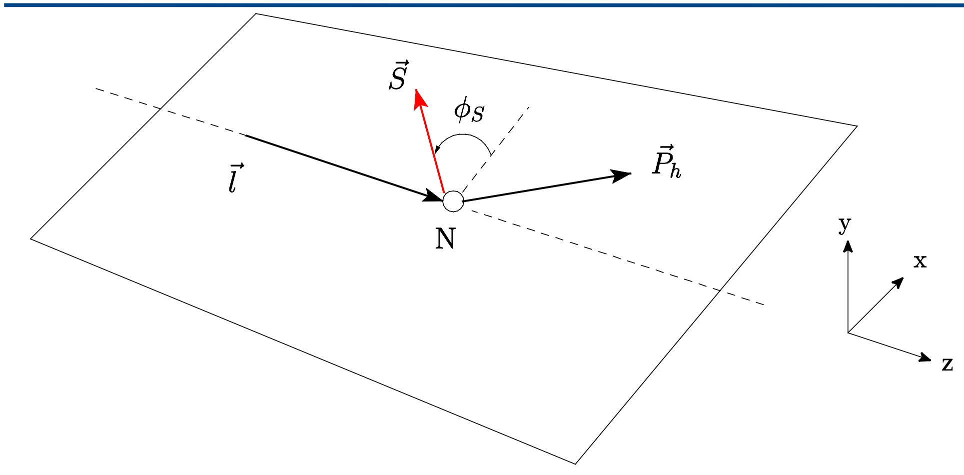
$$\sigma_{UT} \propto \vec{S}_N \cdot \left(\vec{l}\, x \vec{P}_h\right) \square \sin\left(\varphi_S\right)$$

$$A_N\left(x_F, p_T\right) = A_{UT}^{sin\left(\varphi_S\right)}$$

Why a non-zero A_N is interesting?

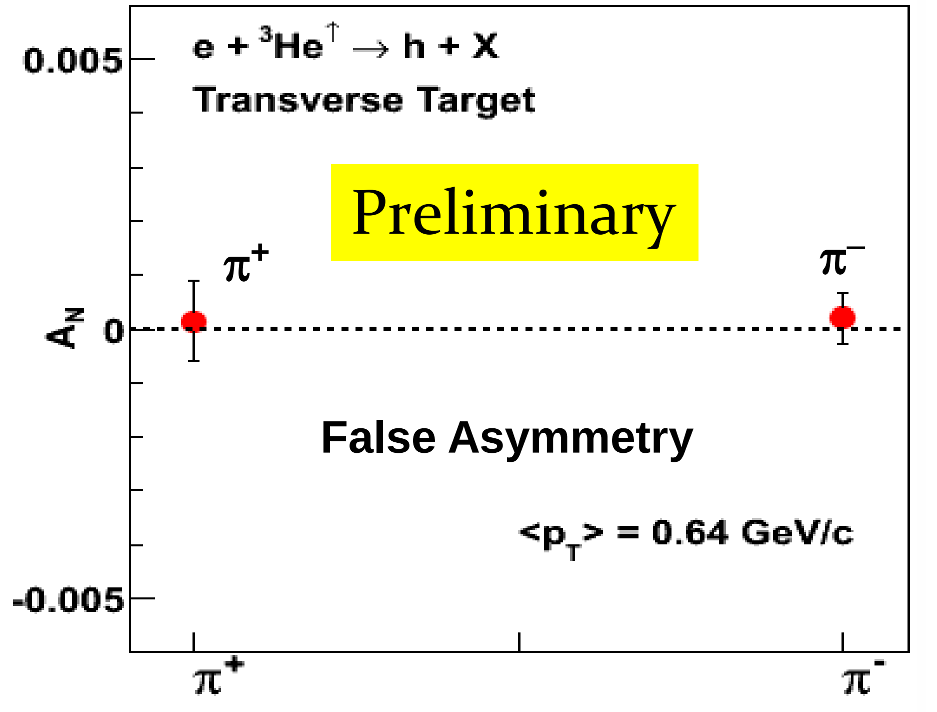
- Analogues to A_N in $pp^\uparrow \rightarrow hX$ collision
- Simpler than $pp^\uparrow \rightarrow hX$ due to only one quark channel
- Same transverse spin effects as SIDIS and *p-p* collisions (Sivers, Collins, twist-3)
- Clean test TMD formalism (at large p_T ~ 1 GeV or more)
- To help understand mechanism behind large A_N in $pp^\uparrow \rightarrow hX$ in the TMD framework

Transverse SSA in Inclusive Hadron



$$\vec{S}_N \cdot \left(\vec{l}\, x \vec{P}_h\right) = 0$$

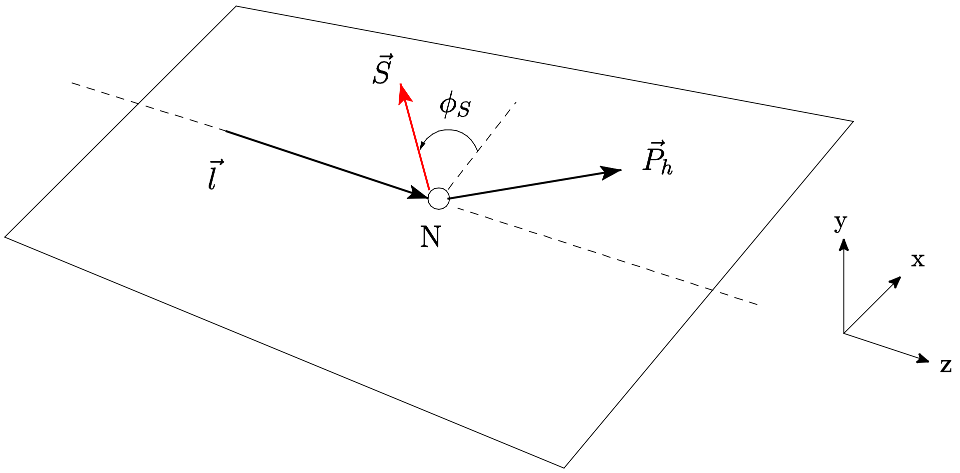
$$A_{UT}^{\sin(\varphi_S)}(\varphi_S = 0)$$



$$A_{UT}^{\sin(\varphi_S)} = \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$

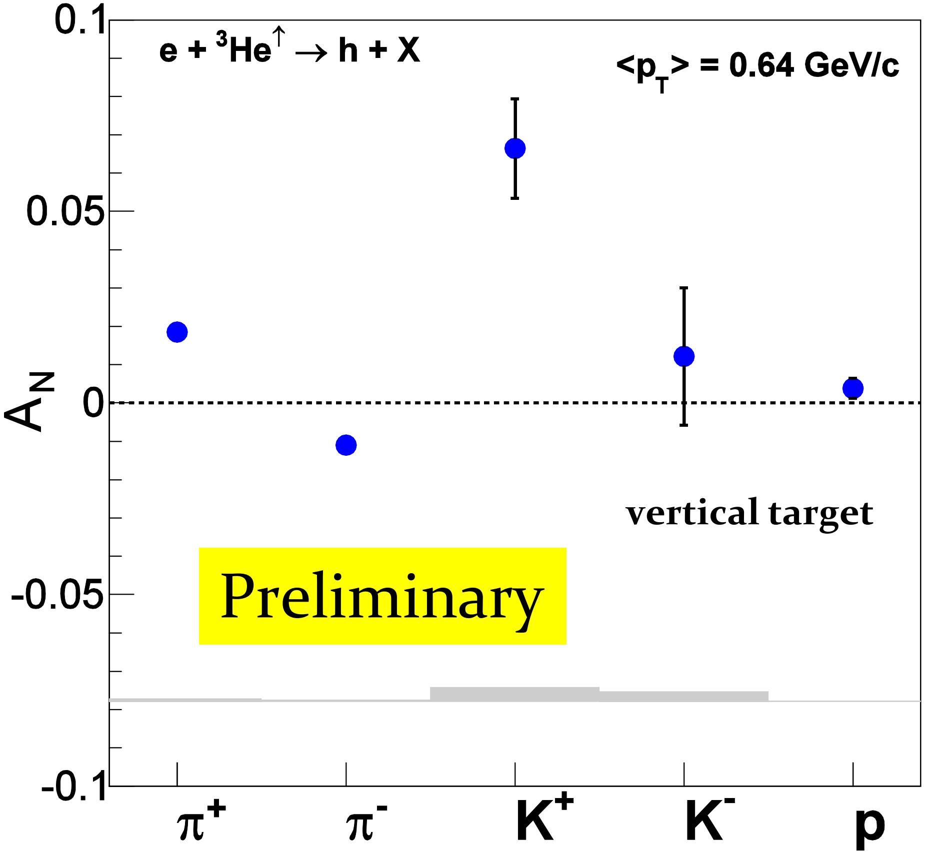
- Target spin flip every 20 minutes
- Acceptance effects cancels
- Overall systematic check with A_N at $\phi_S = 0$
  - False asymmetry < 0.1%

E06-010: Inclusive Hadron SSA (A_N)



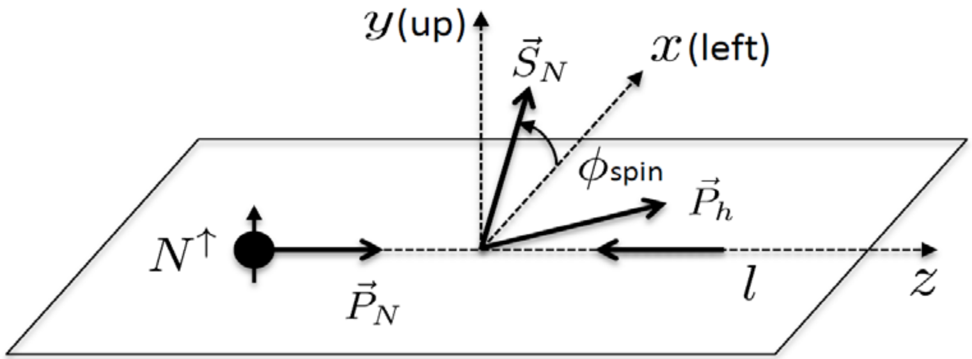
$$\vec{S}_N \cdot \left(\vec{l}\, x \vec{P}_h\right) \neq 0$$

$$A_{UT}^{\sin(\varphi_S)}\left(\varphi_S = 90^0\right)$$



- Clear non-zero vertical target SSA
- Opposite sign for π^+ and π^-
- Large for K^+

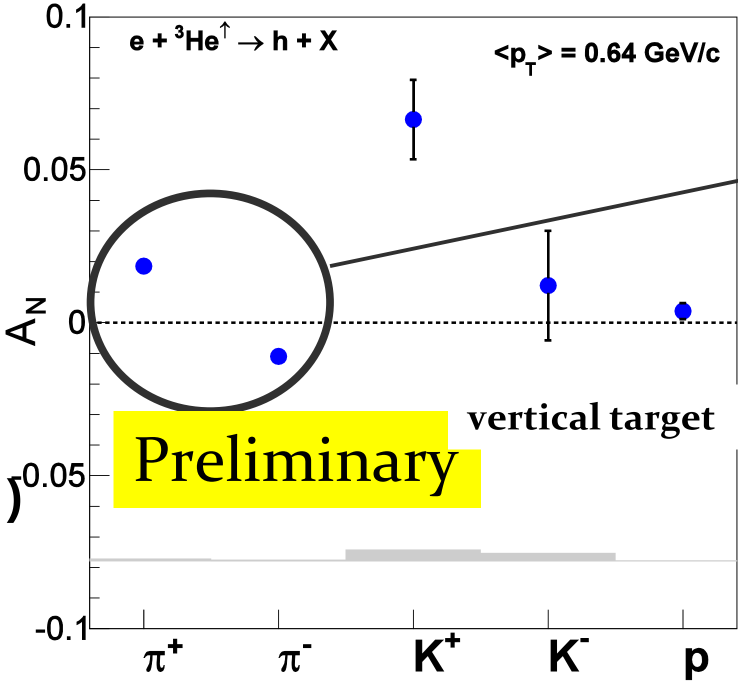
E06-010: Inclusive Hadron SSA (A_N)

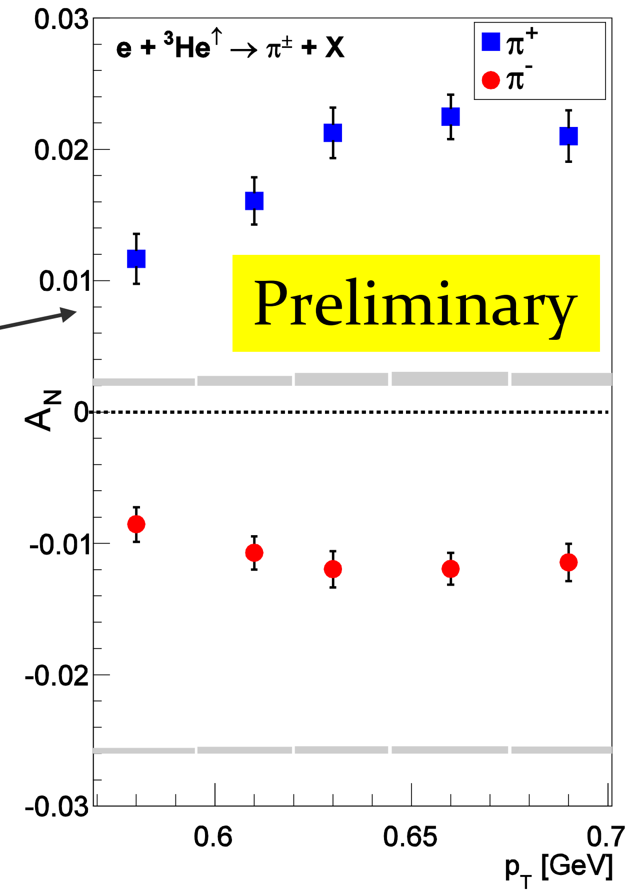


$$\vec{S}_N \cdot \left(\vec{l}\, x \vec{P}_h\right) \neq 0$$

$$A_{UT}^{\sin(\varphi_S)}\left(\varphi_S = 90^0\right)$$

- Clear non-zero target SSA
- Opposite sign for π^+ and π^-
- A_N at low p_T not very well understood
- Results consistent with predictions based on Sivers mechanism (valid at high p_T)





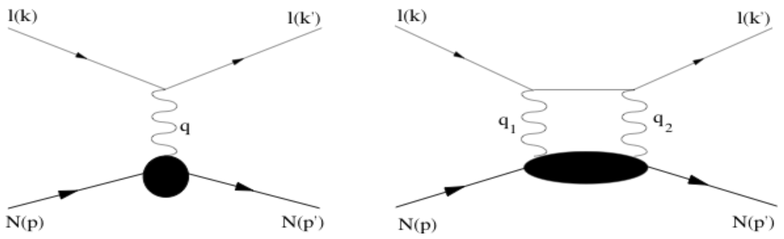
Preliminary New Results (III)from JLab Hall A E06-010 with a polarized ^{3}He (n)

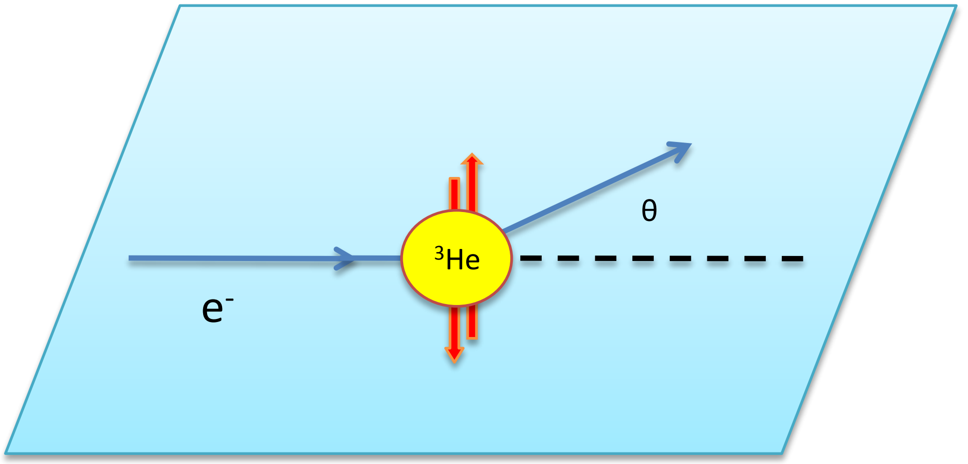
Inclusive Electron SSA

Analysis by J. Katech(W&M), X. Qian (Caltech)

Inclusive Target Single Spin Asymmetry: DIS

$$A_y(Q^2) = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$





- **Unpolarized e^- beam incident on ^{3}He target polarized normal to the electron scattering plane.**

- **However, A_y=0 at Born level,**
  → sensitive to physics at order α^2; two-photon exchange.

$$A_y \propto \frac{Im(T_{1\gamma} T_{2\gamma}^{*})}{|T|^2}$$

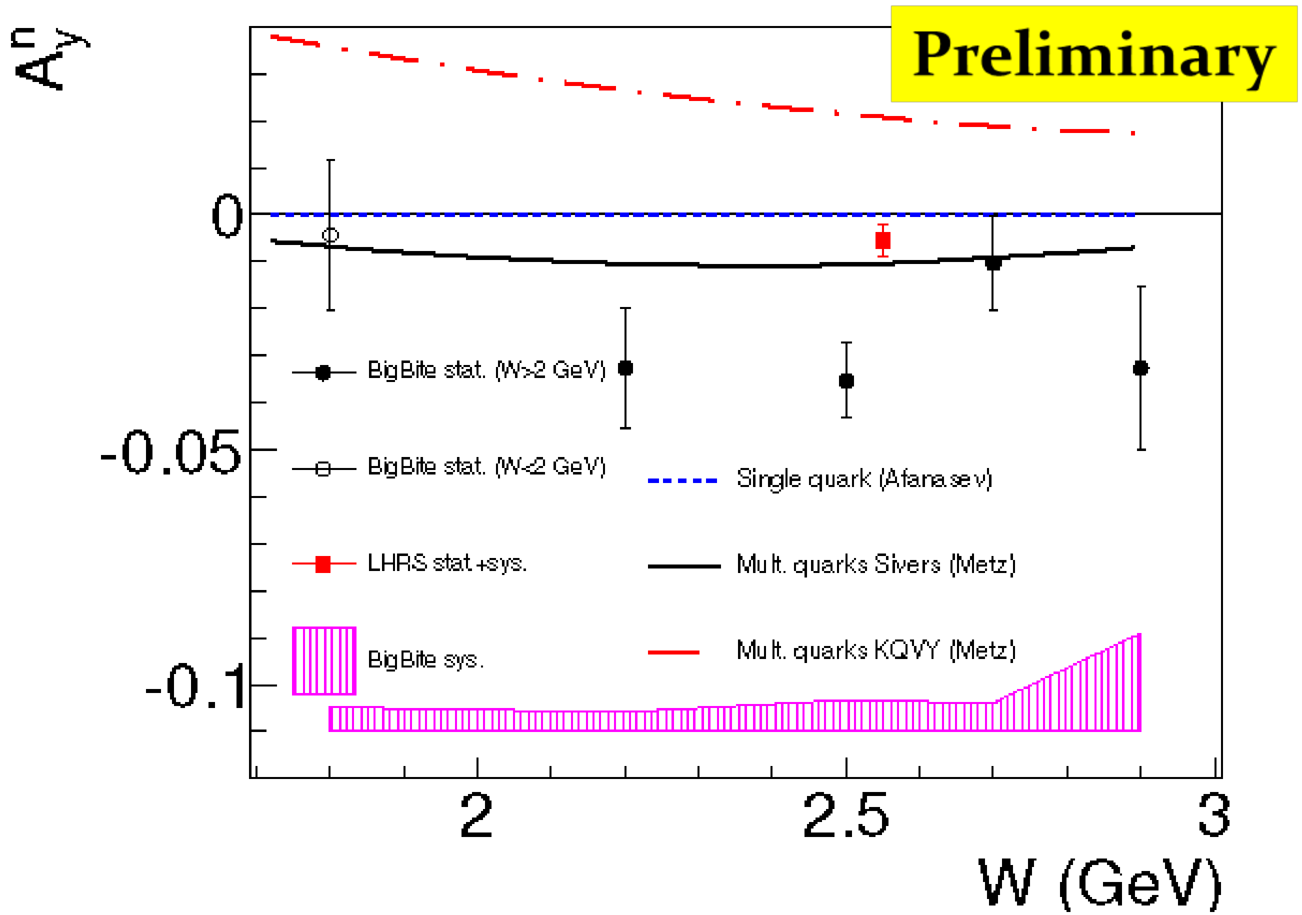
- **In DIS case: related to integral of Sivers**
- **Physics Importance discussed in A. Metz's paper**

Inclusive Target Single-Spin Asymmetry

Extracted neutron SSA from ^{3}He(e,e')

Vertically polarized target

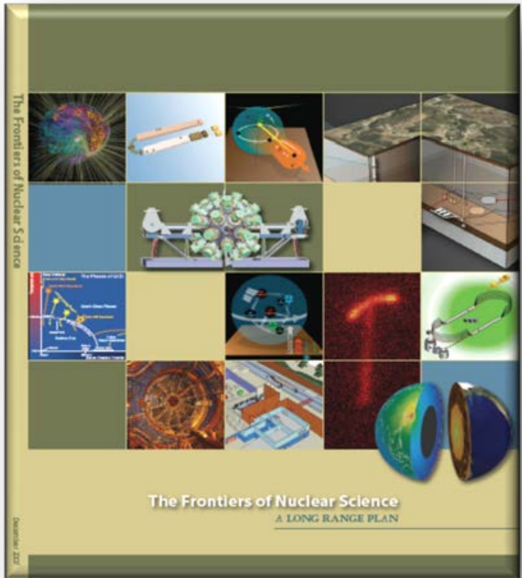
- **Results show 2-photon effects**
- **Consistent with A. Metz's prediction: 2-photon interact with 2 quarks and q-g-q correlator from Torino fit for Sivers (solid black)**
- **Disagree with predictions based on KQW q-g-q correlator (red-dashed)**
- **Disagree with predictions based on 2-photon interact with 1 quark (blue dashed)**



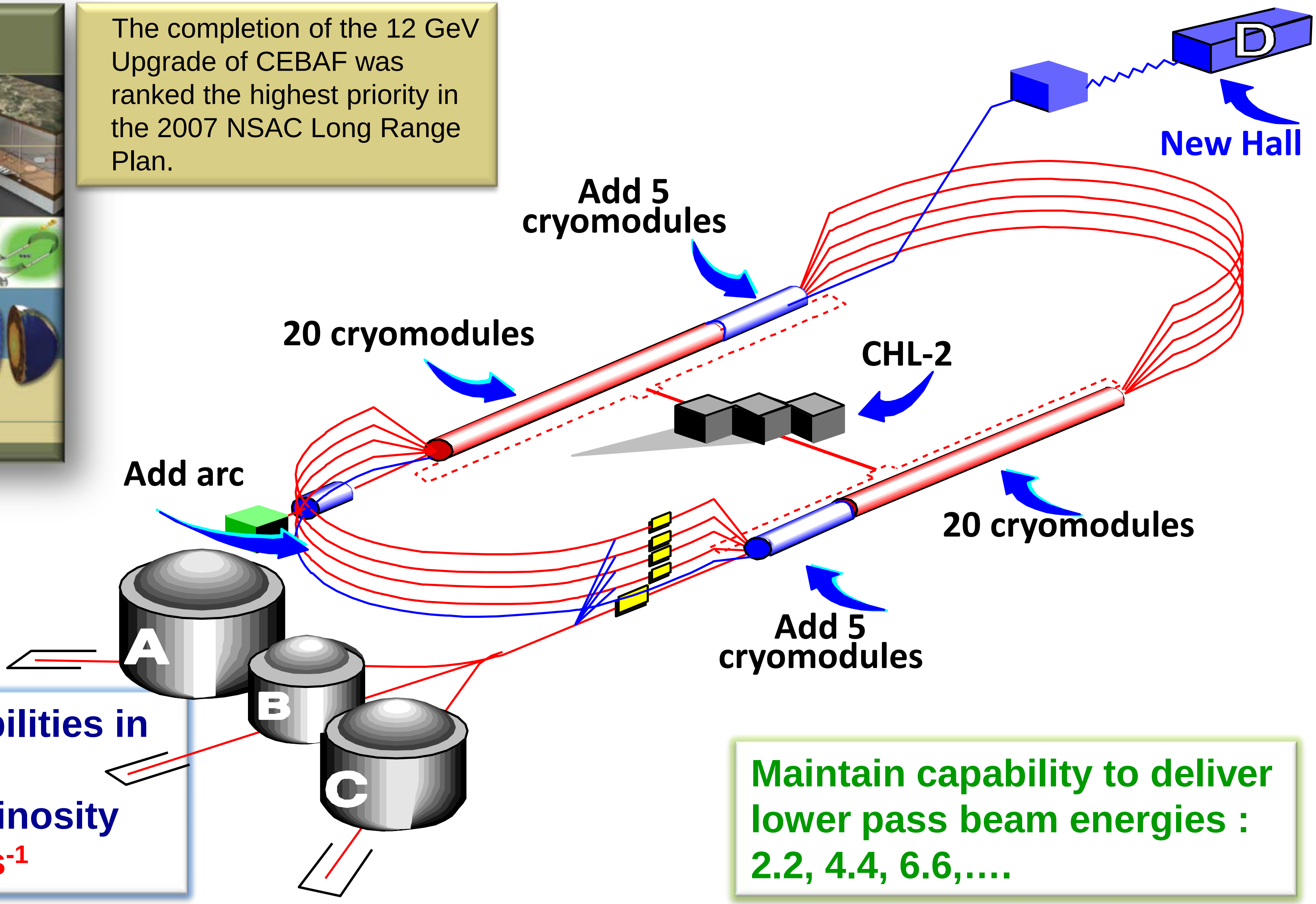
Future: TMD study with SoLID at 12 GeV JLab Hall A

Precision 4-D mapping of TMD asymmetries
with Polarized ^{3}He (Neutron) and Proton

JLab 12 GeV Upgrade



The completion of the 12 GeV Upgrade of CEBAF was ranked the highest priority in the 2007 NSAC Long Range Plan.

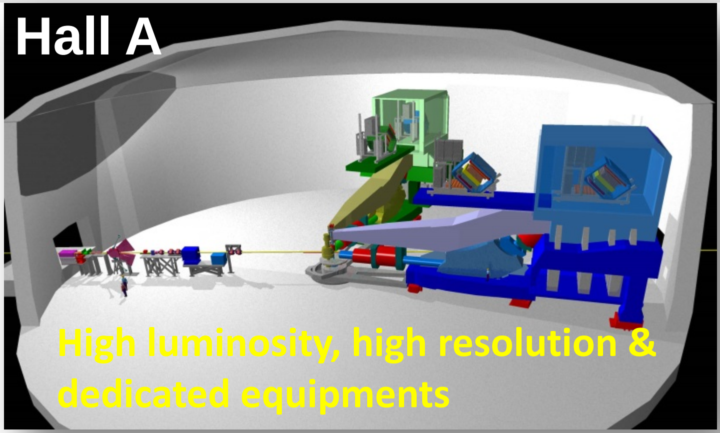


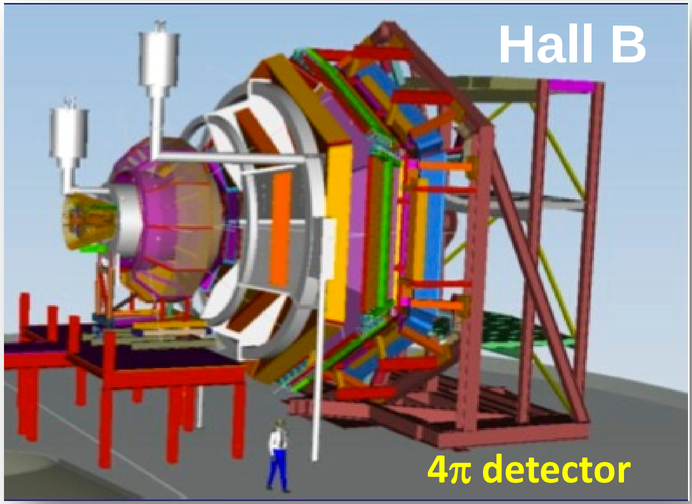
- Enhanced capabilities in existing Halls
- Increase of Luminosity 10^{35} - ~10^{39} cm^{-2}s^{-1}

Maintain capability to deliver lower pass beam energies : 2.2, 4.4, 6.6,….

JLab Physics Program at 12 GeV

Hall A *– form factors, GPDs & TMDs , SRC*
Low-energy tests of the SM and Fund. Symmetry Exp

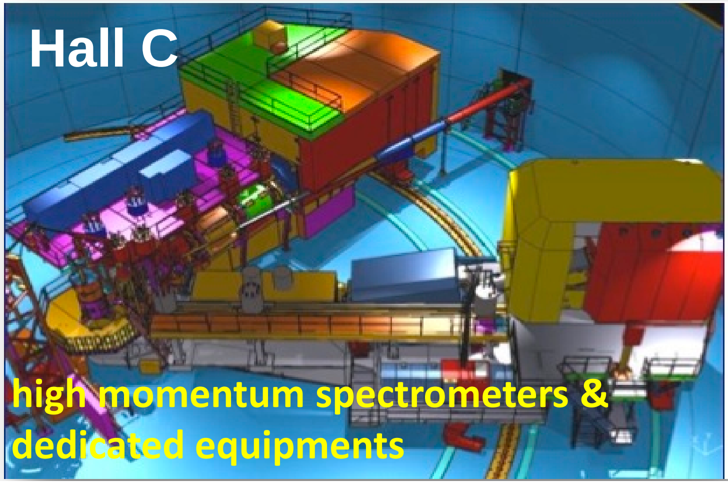


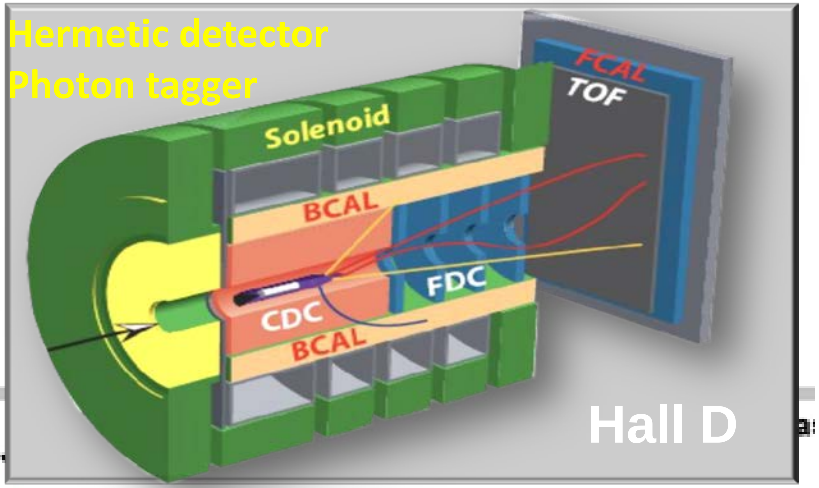


SoLID, MOLLER.

Hall B - *3-D nucleon structure via GPDs & TMDs*
Search new form of hadron. matter via Meson Spectr.

Hall C *– precision determination of valence quark properties in nucleons and nuclei*





Hall D *- exploring origin of confinement by studying exotic mesons using real photons*

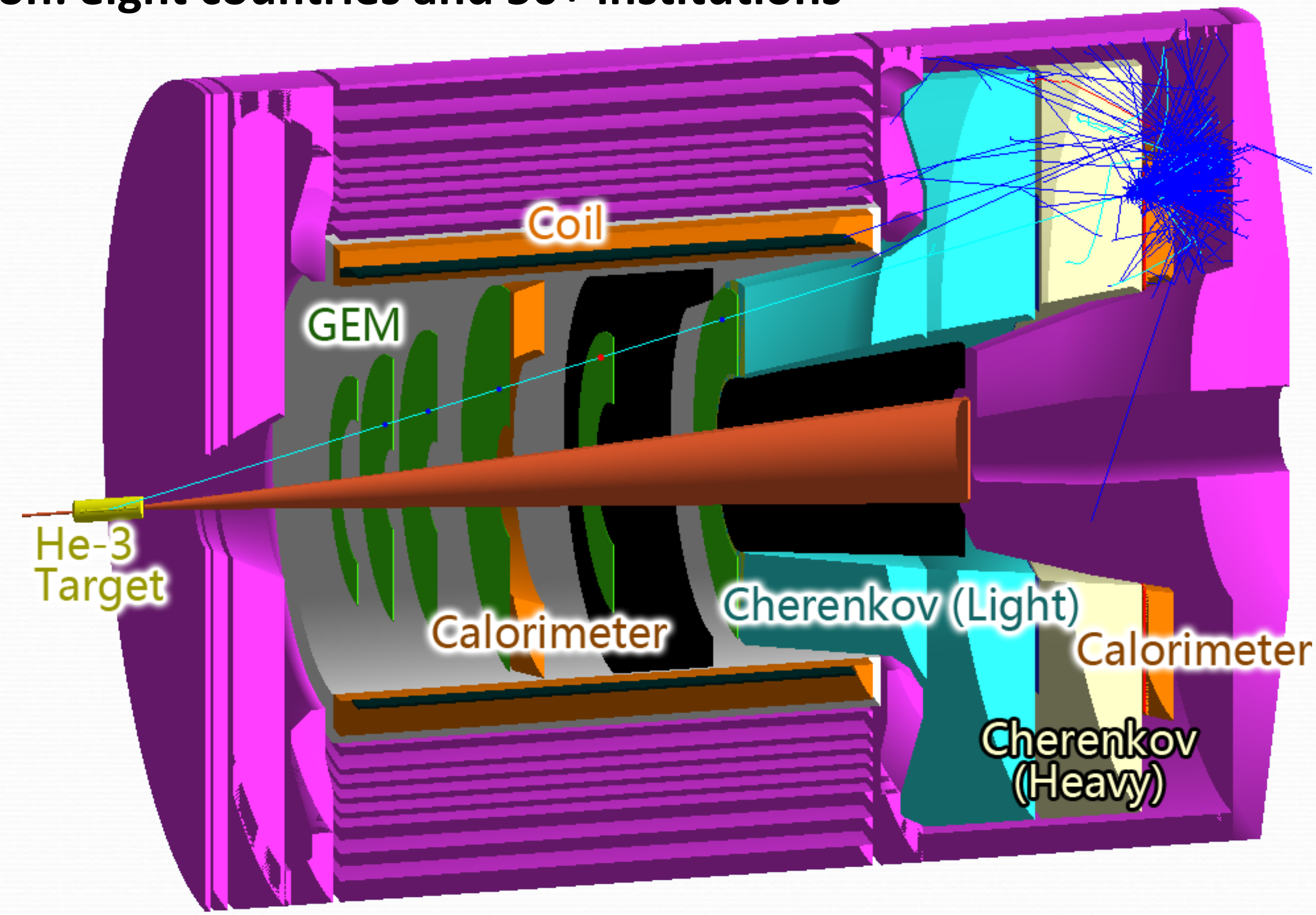
JLab 12 GeV Era: Precision Study of *TMDs*

- From exploration to precision study with 12 GeV JLab
- Transversity: fundamental *PDF*s, tensor charge
- *TMD*s: 3-d momentum structure of the nucleon
- → Quark orbital angular momentum
- Multi-dimensional mapping of *TMD*s
  - 4-d ($x,z,P_{\perp},Q^2$)
  - Multi-facilities, global effort
- Precision → high statistics
  - high luminosity and large acceptance

SoLID for SIDIS/PVDIS with 12 GeV JLab

- Exciting physics program:
  Five approved experiments:
  three SIDIS "A rated", one PVDIS "A rated", one J/Psi "A- rated"
- International collaboration: eight countries and 50+ institutions

- CLEOII Magnet
- GEMs for tracking
- Cherenkov and EM Calorimeter for electron PID
- Heavy Gas Cherenkov and MRPC (TOF) for pion PID



E12-10-006/E12-11-108, Both Approved with "A" Rating

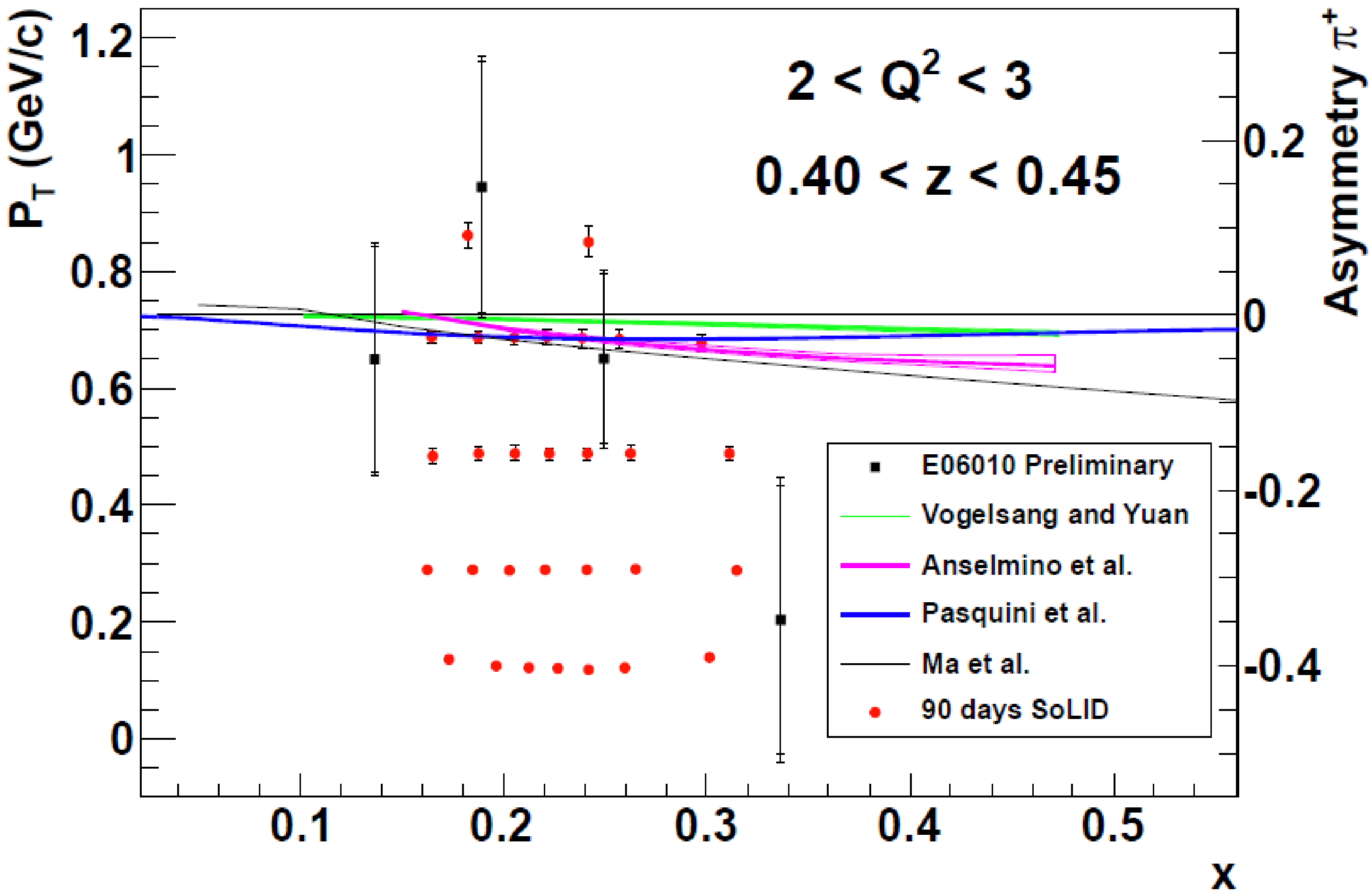
Mapping of Collins(Sivers) Asymmetries with SoLID

E12-10-006 3He(n), Spokespersons: J. P. Chen, H. Gao, X. Jiang, J-C. Peng, X. Qian
E12-11-007(p) , Spokespersons: K. Allda, J. P. Chen, H. Gao, X. Li, Z-E. Mezinai

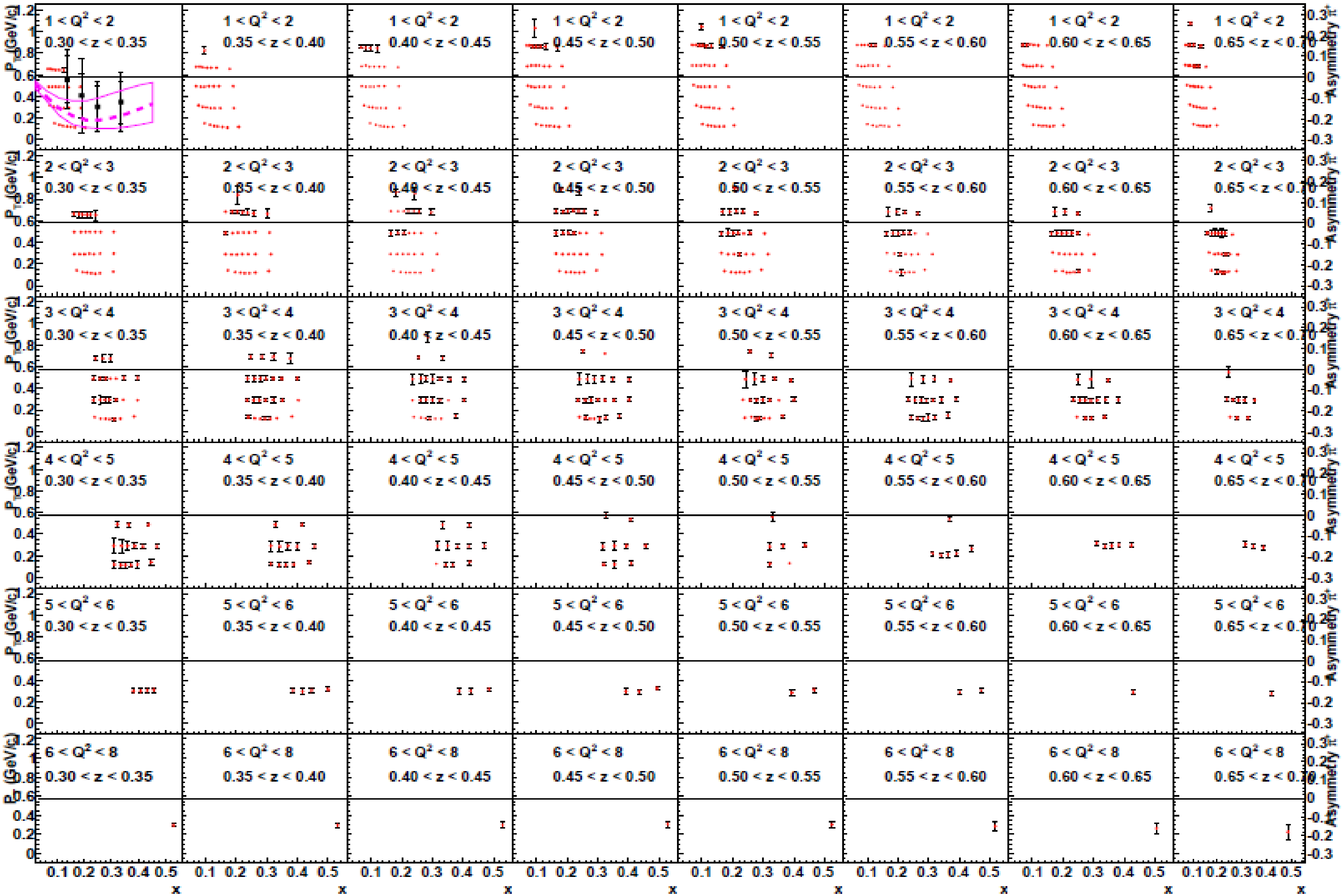
Collins Asymmetry

- Both π+ and π-
- Precision Map in region
  x(0.05-0.65)
  z(0.3-0.7)
  Q^2(1-8)
  P_T(0-1.6)

- <10% d quark tensor charge

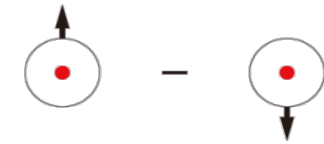


Map Collins and Sivers asymmetries in 4-D (x, z, Q^2, P_T)

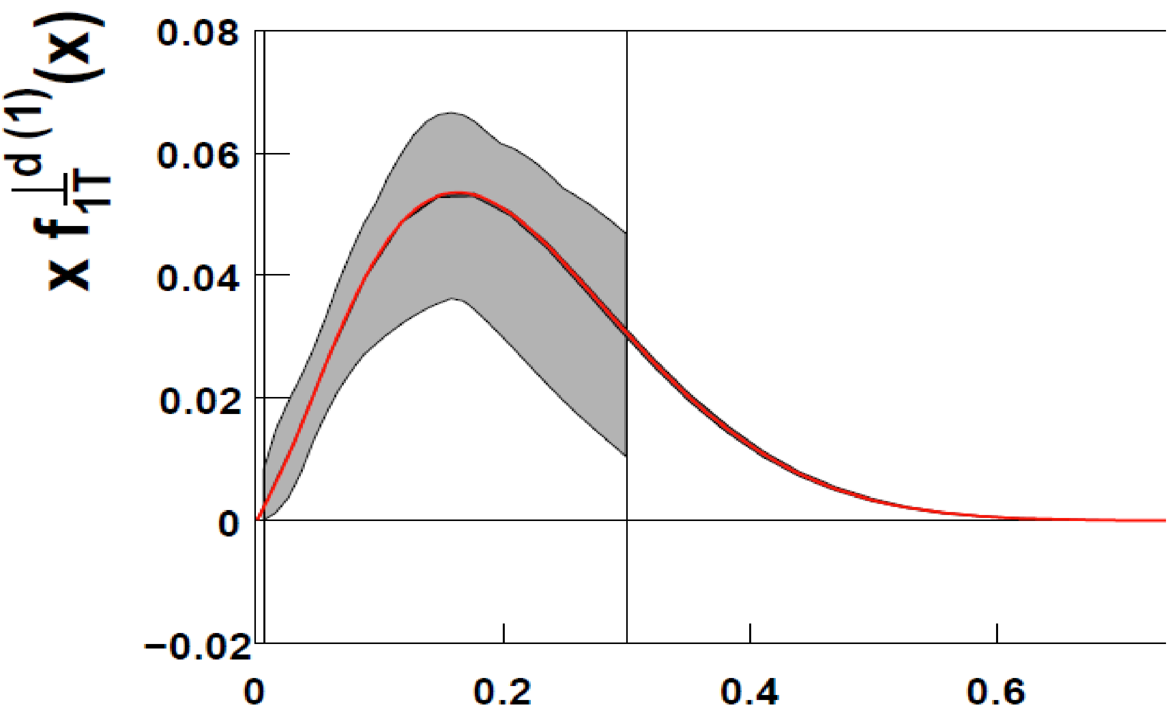


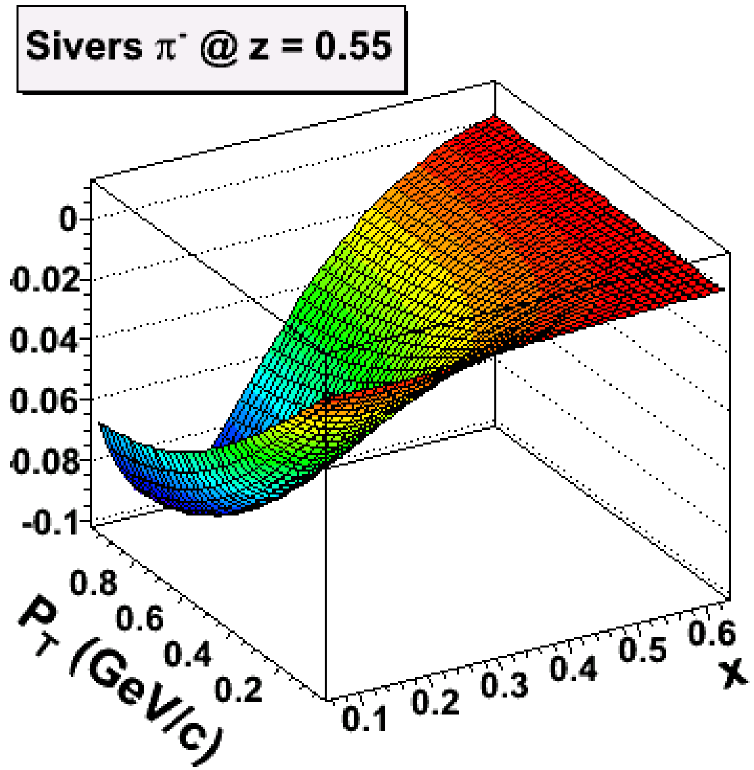
Expected Improvement: Sivers Function

$f_{1T}^{\perp}$ =



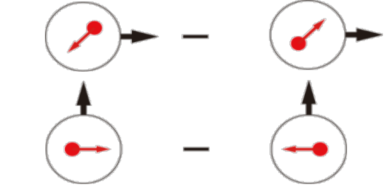
- Significant Improvement in the valence quark (high-x) region
- Illustrated in a model fit (from A. Prokudin)



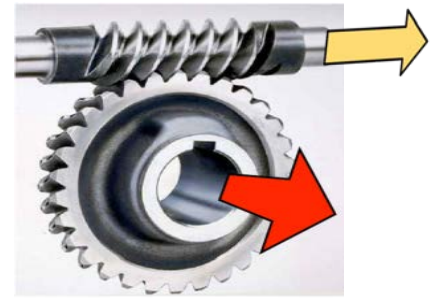


E12-11-107: Worm-gear functions ("A' rating:)

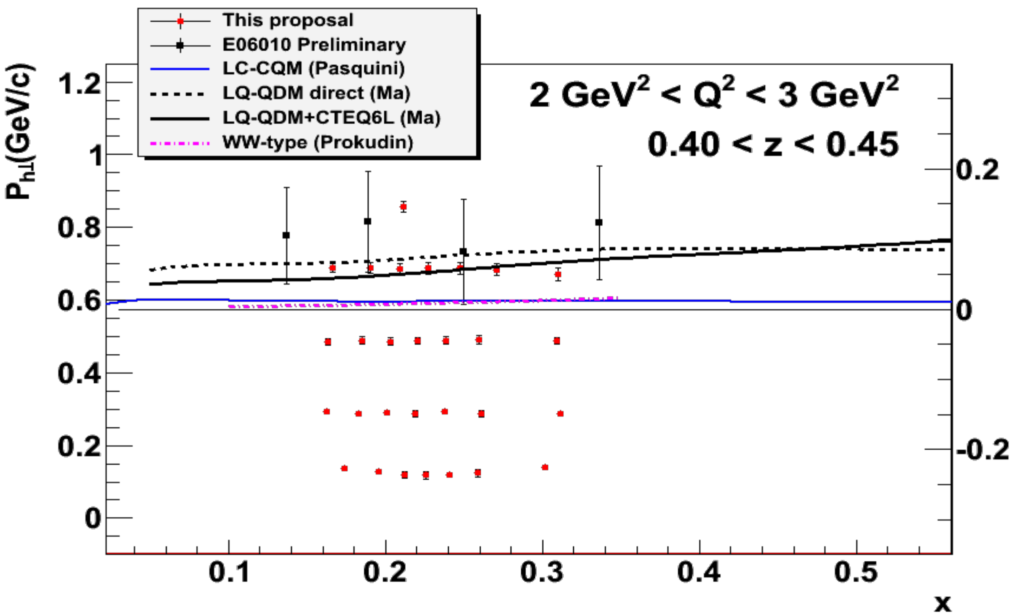
Spokespersons: J. P. Chen/J. Huang/Y. Qiang/ W. Yan



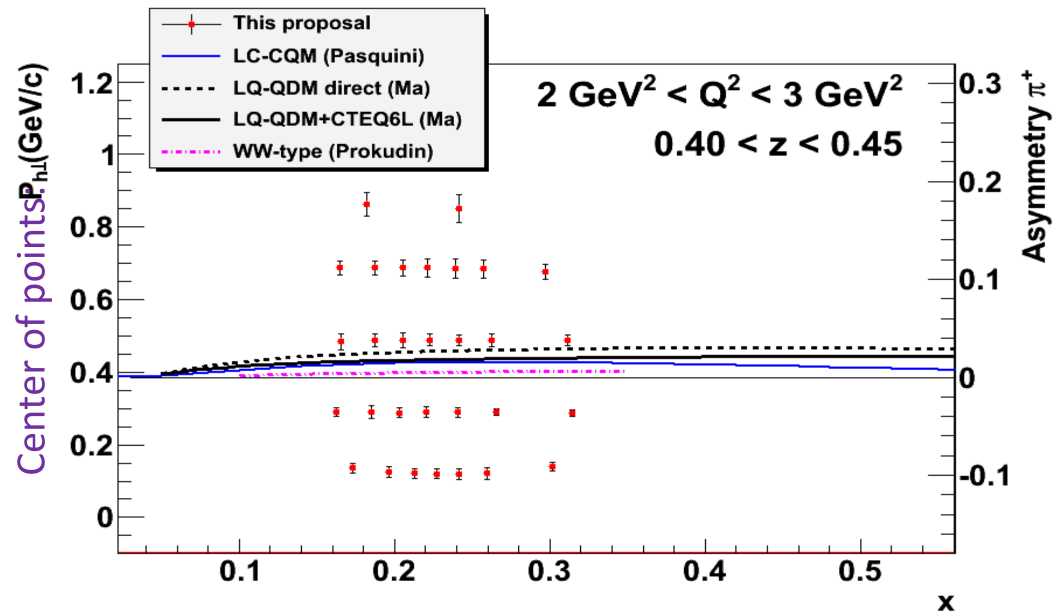
- Dominated by real part of interference between L=0 (S) and L=1 (P) states
- No GPD correspondence
- Lattice QCD -> Dipole Shift in mom. space.
- Model Calculations -> $h_{1L}^{\perp}$ =? $-g_{1T}$.



Longi-transversity
Trans-helicity



$$A_{LT} \sim g_{1T}(x) D_1(z)$$



$$A_{UL} \sim h^{\perp}{}_{1L}(x) H^{\perp}{}_1(z)$$

Summary on SoLID TMD Program

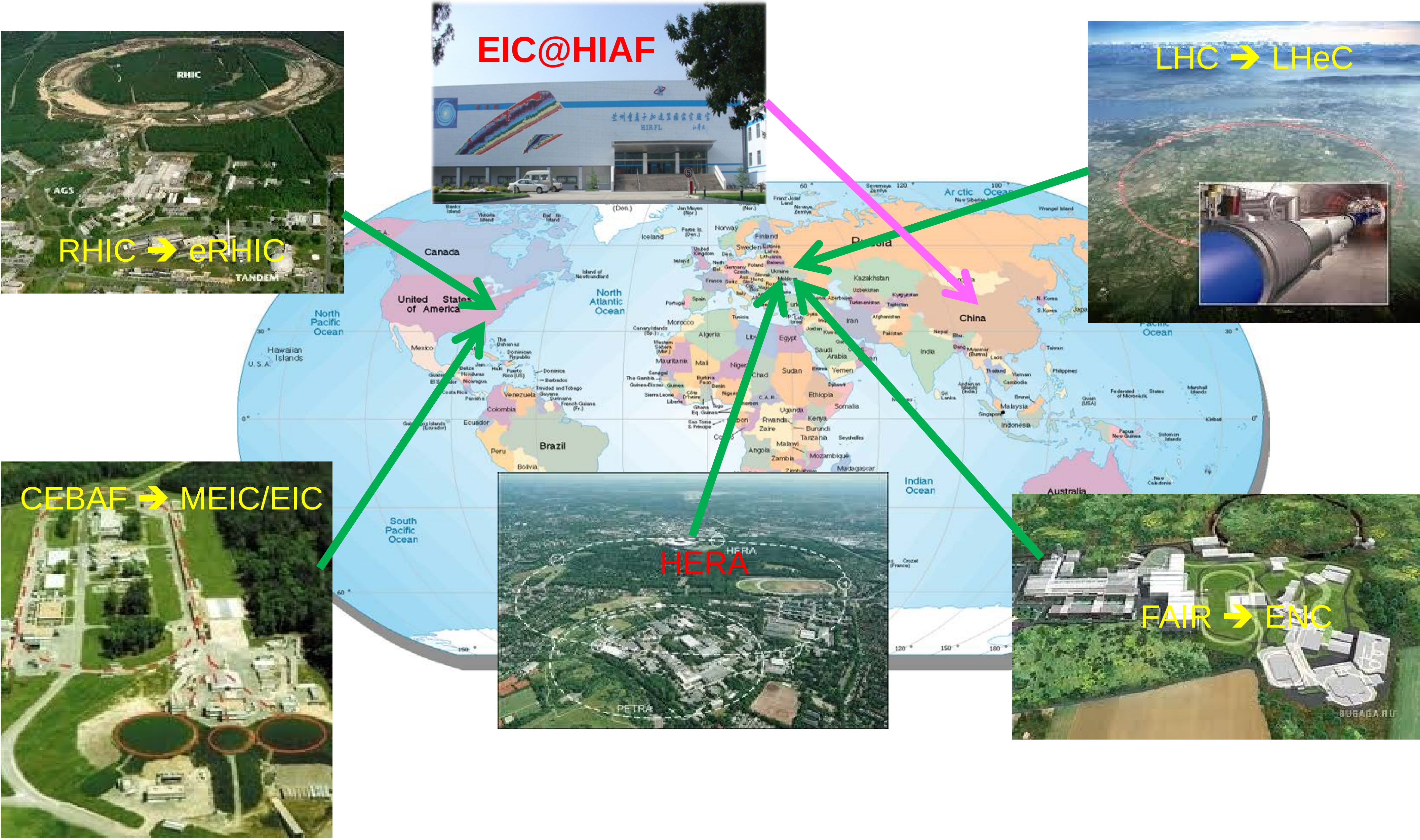
- Unprecedented precision *4-d* mapping of SSA
  - Collins, Sivers, Pretzelosity and Worm-Gear
- Both polarized ^{3}He (n) and polarized proton with SoLID
- Three “A” rated experiments approved. One LOI on di-hadron.
- Study factorization with *x* and *z*-dependences
- Study P_T dependence
- Combining with the world data
  - extract transversity and fragmentation functions for both *u* and *d* quarks
  - determine tensor charge
  - study TMDs for both valence and sea quarks
  - learn quark orbital motion and quark orbital angular momentum
  - study Q^2 evolution
- Global efforts (experimentalists and theorists), global analysis
  - much better understanding of multi-d nucleon structure and QCD
- **Welcome new collaborators**

Long-term Future: TMD study with EIC

MEIC@JLab and E-RHIC@BNL

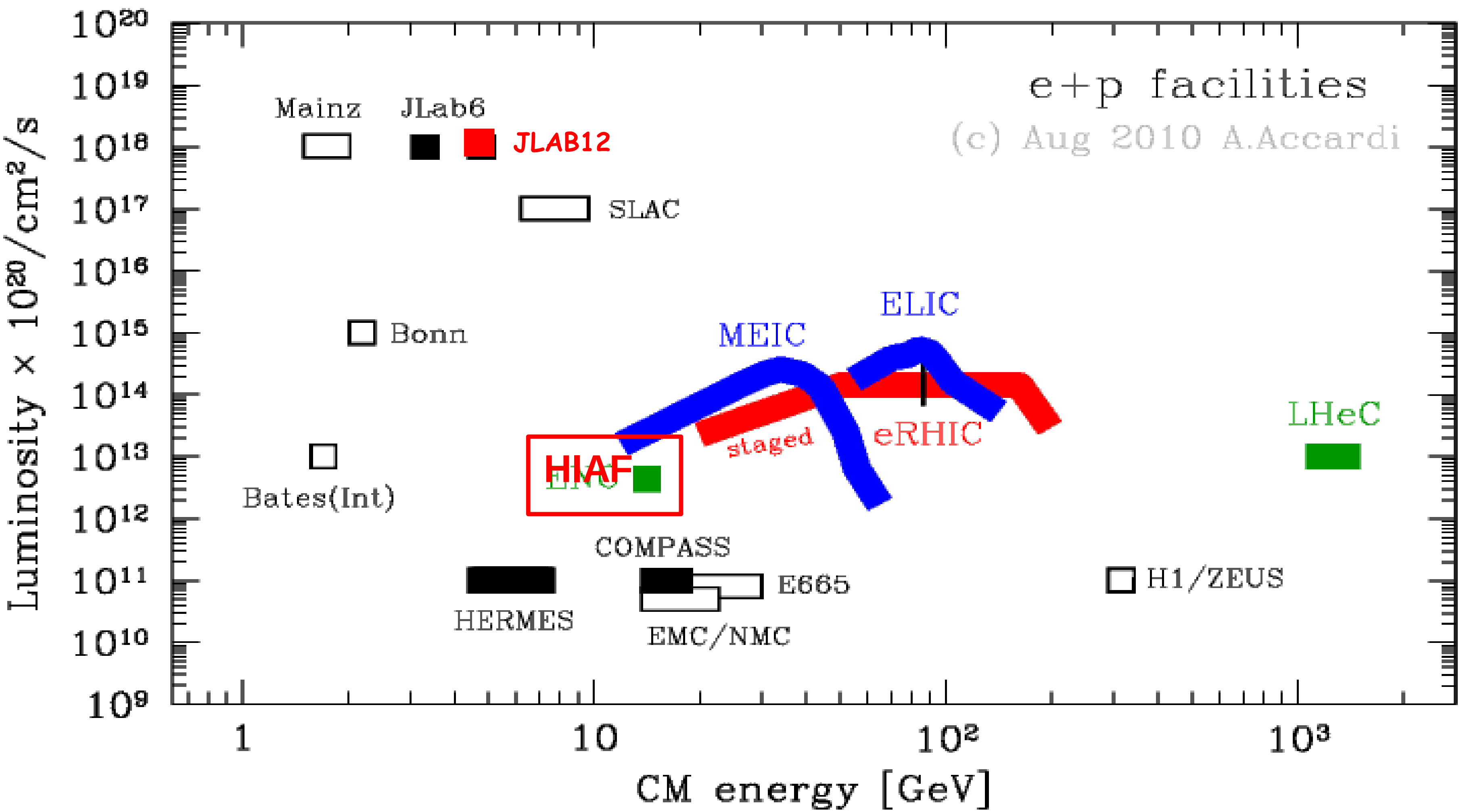
A New Opportunity: EIC in China

Electron Ion Colliders on the World Map



Lepton-Nucleon Facilities

EIC@HIAF: e(3GeV) +p(12GeV), both polarized, L(max)=$4x10^{32}cm^2/s$



EIC@HIAF Kinematic Coverage Comparison with JLab 12 GeV

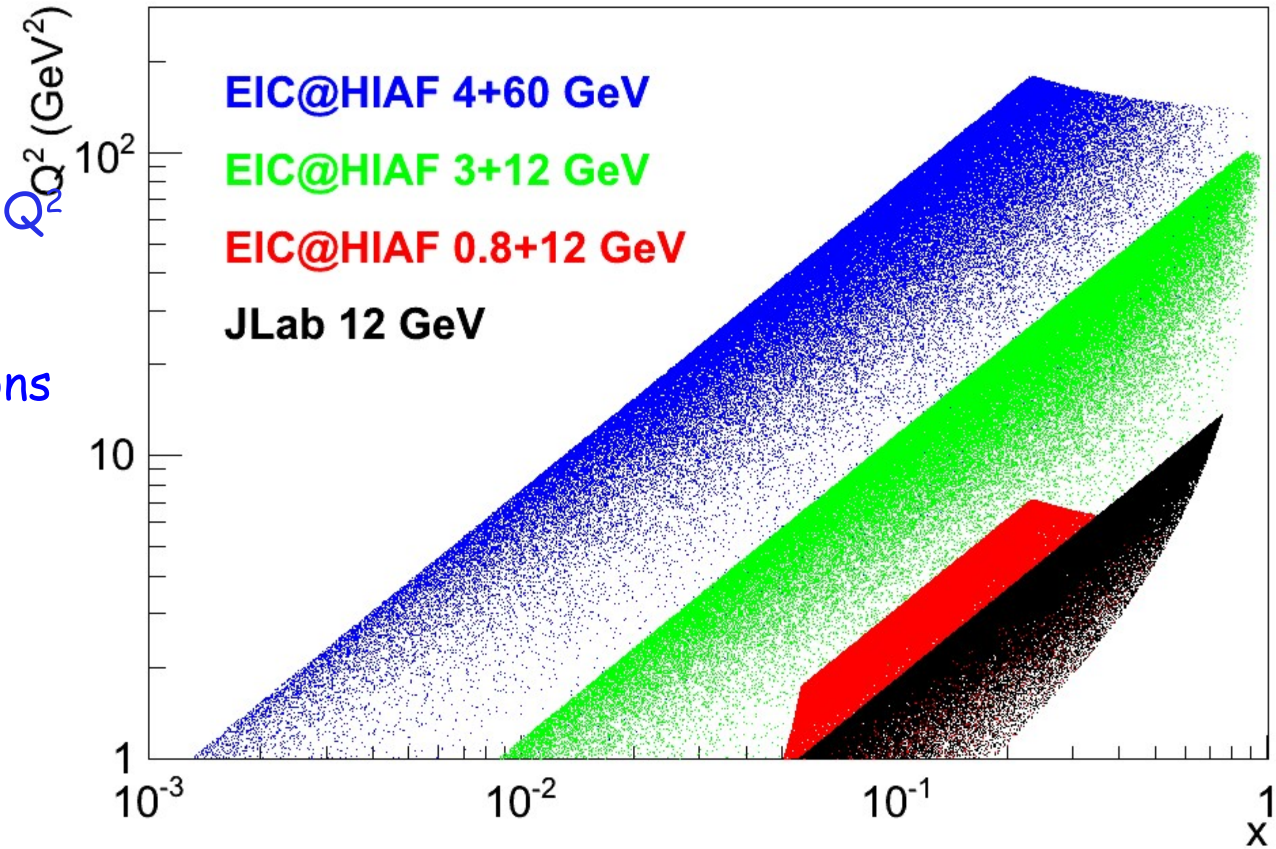
e(3GeV) +p(12GeV), both polarized, L(max)=$4 \times 10^{32} cm^2/s$

EIC@HIAF:

- study sea quarks (x > 0.01)
- deep exclusive scattering at Q^2 > 5-10
- higher Q^2 in valance region
- range in Q^2 allows study gluons

- Timeline:

Funding Approved for HIAF
EIC under design/discussion
Construction 2014-2019



plot courtesy of Xurong Chen (IMP)

Science Goals

The Science of eRHIC/MEIC

Goal: Explore and Understand QCD:

Map the spin and spatial structure of quarks and gluons in nucleons

Discover the collective effects of gluons in atomic nuclei

(role of gluons in nuclei & onset of saturation)

Emerging Themes:

Understand the emergence of hadronic matter from quarks and gluons & EW

The Science of EIC@HIAF

One Main Goal: Explore Hadron Structure

Map the spin-flavor, multi-d spatial/momentum structure of valence & sea quarks

TMD Study and other Programs at EIC@China

- Unique opportunity for TMD in "sea quark" region

  reach x ~ 0.01 (JLab12 mainly valence quark region, reach down to x ~ 0.1)
- Significant increase in Q^2 range for valence region

  energy reach Q^2 ~40 GeV^2 at x ~ 0.4 (JLab12, $Q^2 < 10$)
- Significant increase in P_T range

  reach >1 GeV? (TMD/co-linear overlap region) (JLab12, reach ~ 1 GeV)
- Other Physics Programs:

  Nucleon spin-flavor structure (polarized sea, Δs)

  3-d Structure: GPDs (DVMP, pion/Kaon)

  e-A to study hadronization

  Pion/Kaon structure functions

  ……

  2nd Conference on QCD and Hadron Physics:
  http://qcd2013.csp.escience.cn/dct/page/1

Whitepaper on EIC@China is being worked on:

need inputs and help from international community

Summary

- Nucleon Spin and TMD study have been exciting and fruitful
- Recent and Preliminary Results from JLab with transversely polarized targets: g_2, TMDs
- **JLab 12 GeV**

  Planned SoLID program with JLab12

  Precision 4-d mapping of TMD asymmetries
- Longer-term future: EIC in US

  New possibility: EIC@HIAF in China

  Exciting new opportunities

Precision experimental data + development in theory for Nucleon Spin/TMD +…

➢ lead to breakthrough in understanding QCD?